JULY, 1958

JOURNAL OF THE IRON AND STEEL INSTITUTE

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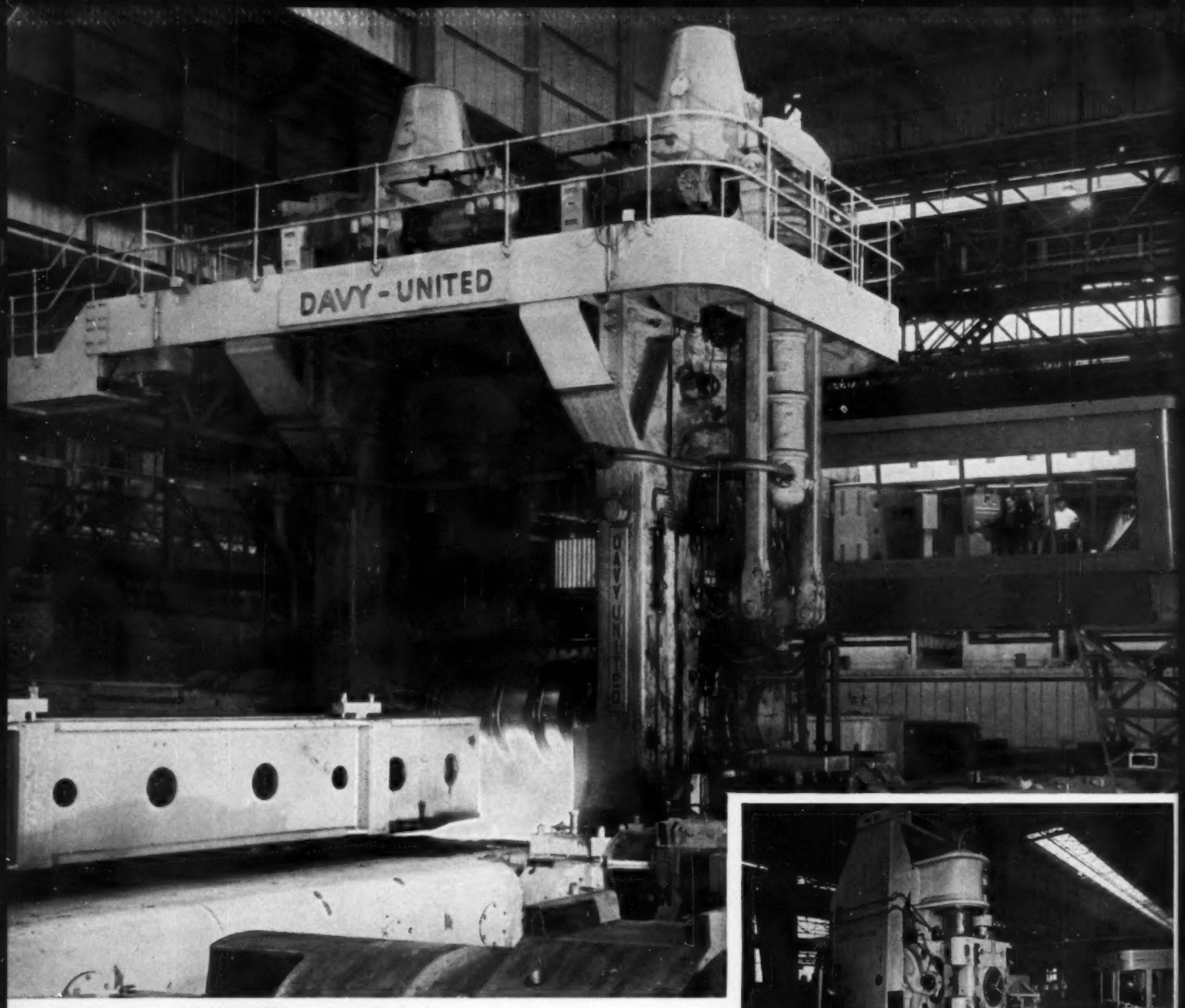
VOL. 189 PART 3

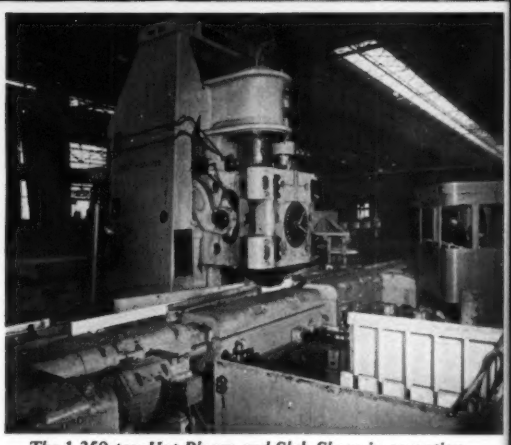
Principal Contents

Report of Annual General Meeting 1958 197
Bessemer Steel in Sweden *by P. Carlberg* 201
Open-hearth Steelmaking in the U.S.A. *by M. W. Lightner and D. L. McBride* 205
Distortion of Die Steels *by K. Sachs* 216
Determination of Boron *by the B.I.S.R.A. Methods of Analysis Committee* 227
Reduction Test for Blast-furnace Burdens *by R. Linder* 233
Alloys of Iron with Ru, Rh, Pd, and Ag *by W. S. Gibson and W. Hume-Rothery* 243
Stability of Graphite, Iron, and Carbides *by D. I. Cameron* 251
Diffusion of Carbon in Si–Fe Alloy *by D. A. Leak and G. M. Leak* 256
Correspondence on Hot-topping 263
News 269 Abstracts 273

A full list of contents is given on the Title Page (see page 67, Advertisement Section)



The Blooming and Slabbing Mill in action at Lackenby.



The 1,350 ton Hot Bloom and Slab Shear in operation.

DAVY-UNITED AT DORMAN LONG

The new Davy-United 52″ × 112″ Reversing Blooming and Slabbing Mill now in production in the Lackenby Works of Dorman Long (Steel) Ltd., is the largest of its type so far installed in Britain. It forms the primary unit of a new plant for producing universal beams which Dorman Long are now bringing into production.

Driven by twin 4,000 h.p. motors, each capable of developing up t 12,000 h.p. on peak loads, the mill is capable of rolling ingots weighin up to 20 tons. It was supplied along with a 1,350 ton hydraulic Ho Bloom and Slab Shear and all necessary handling, transfer an auxiliary equipment.

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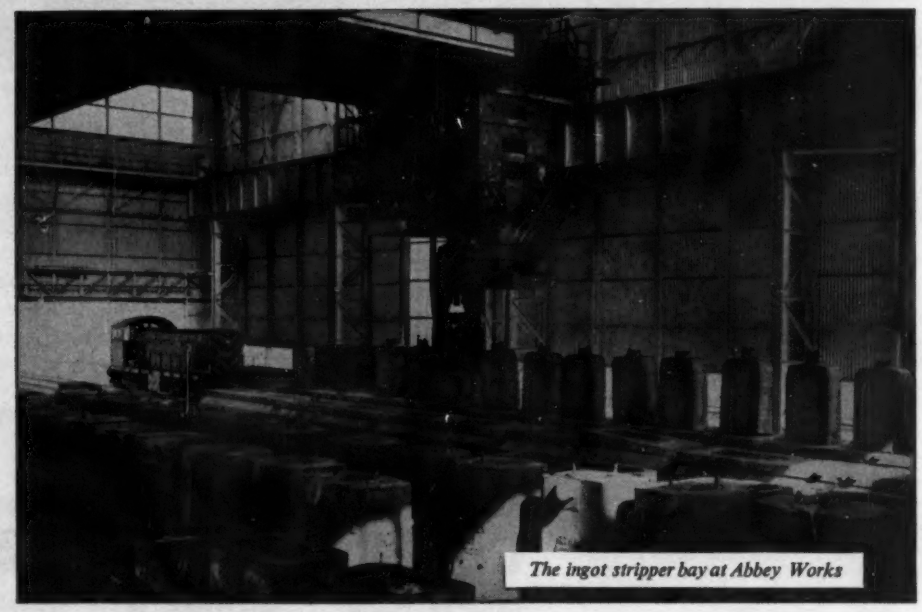
Molten iron being charged into an open hearth furnace at Abbey Works



The ingot stripper bay at Abbey Works

ENQUIRIES

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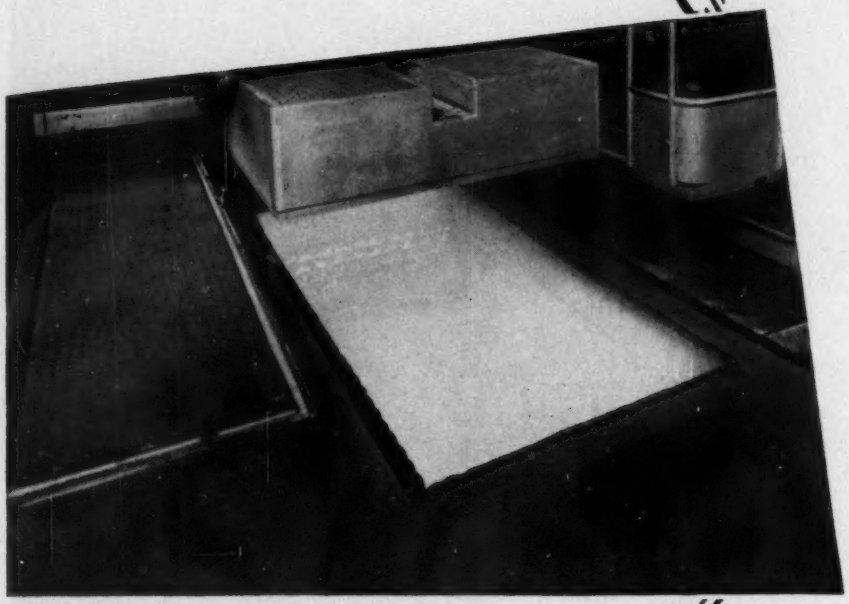
The slabbing mill motor room at Abbey Works

Uniform temperature..



Scale-free heating..

This Electric Soaking Pit installed by S. & A. in The Plate Mill of Colvilles Ltd., Motherwell, is used for heating special steels and composites in slab form. The method of heating and neutral atmosphere ensures uniformity of temperature and no scale formation. Holding capacity 40 tons; power input 900 kVA.

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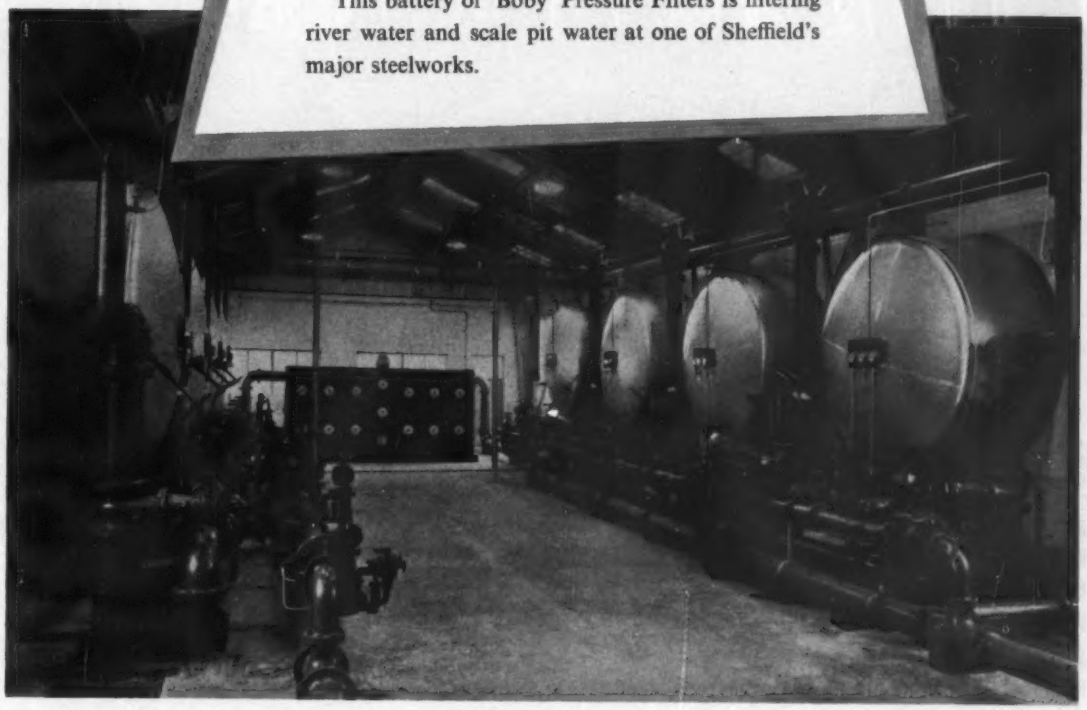
'Boby' Pressure Filters

This battery of 'Boby' Pressure Filters is filtering river water and scale pit water at one of Sheffield's major steelworks.



A notable feature of this 'Boby' Filtration Plant is that the extremely dirty River Don water is filtered successfully without any form of pretreatment.

The filtered water is used for fabric bearing cooling, strip mill cooling sprays, and general steelworks services.

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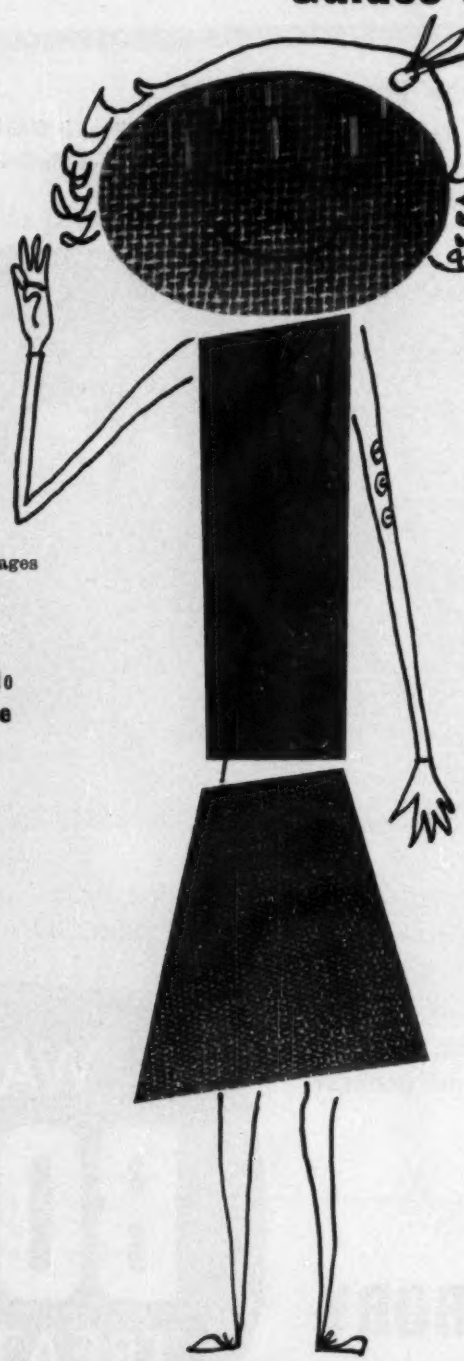

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low coefficient of friction

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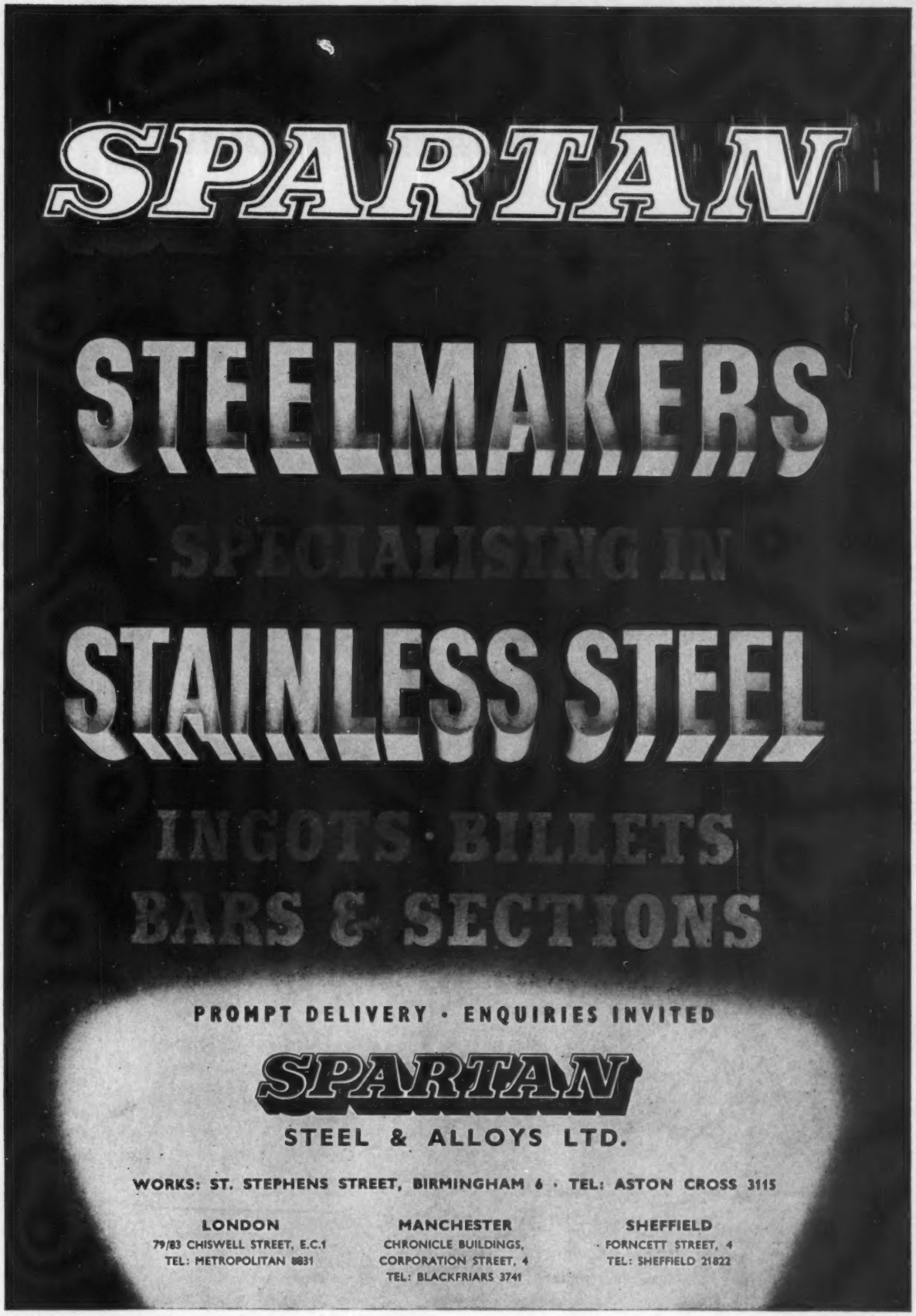
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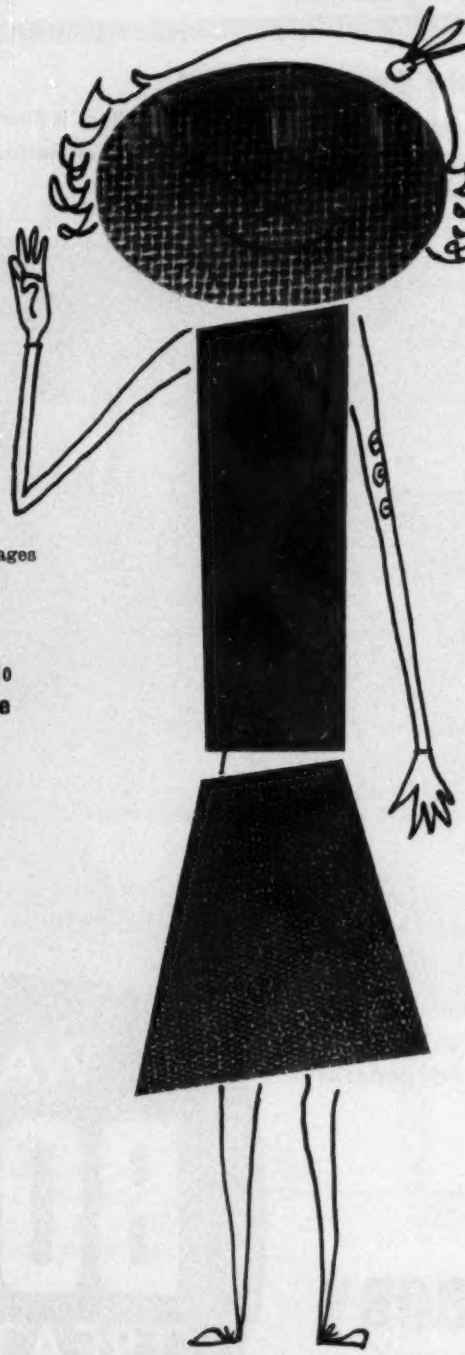

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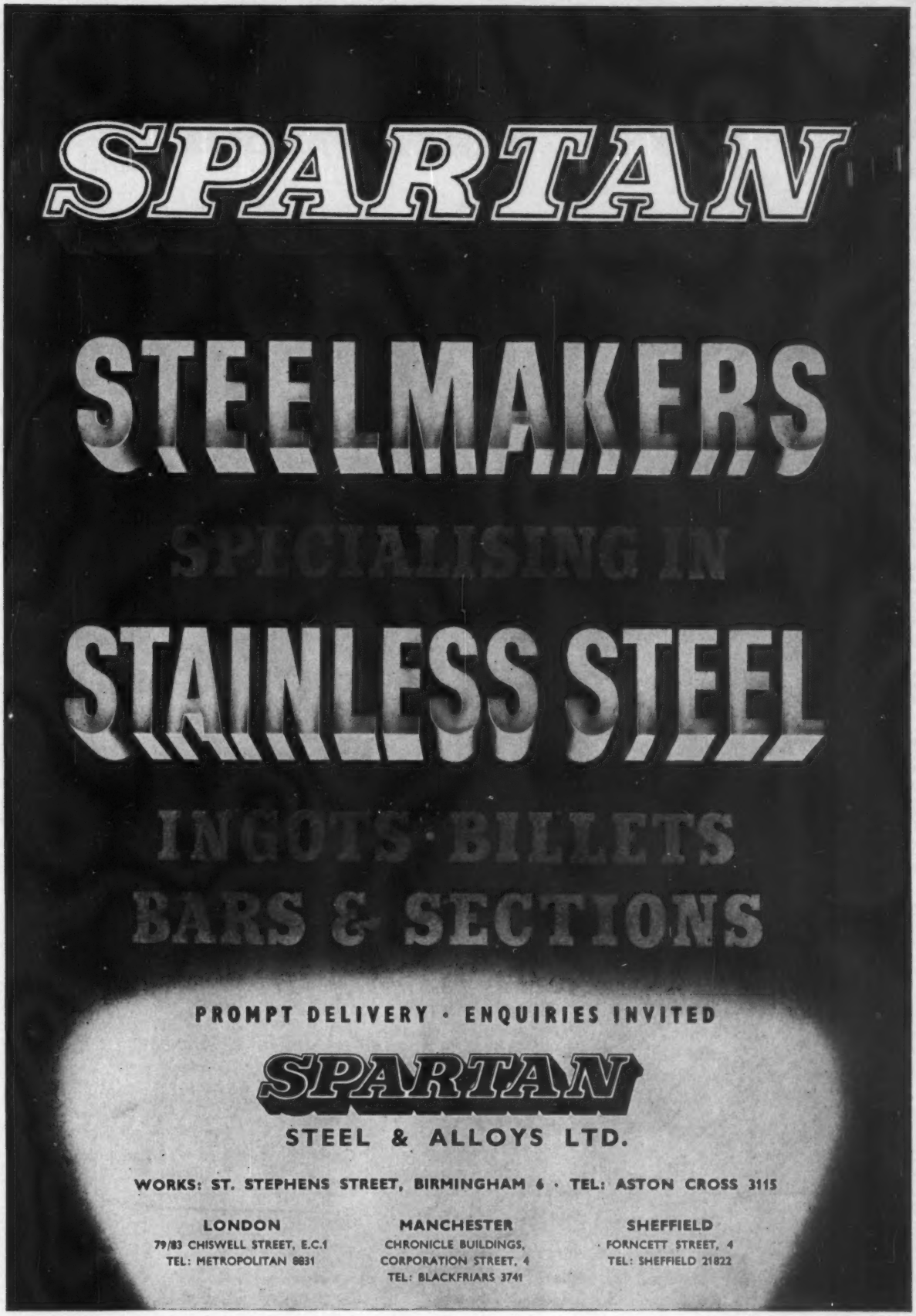
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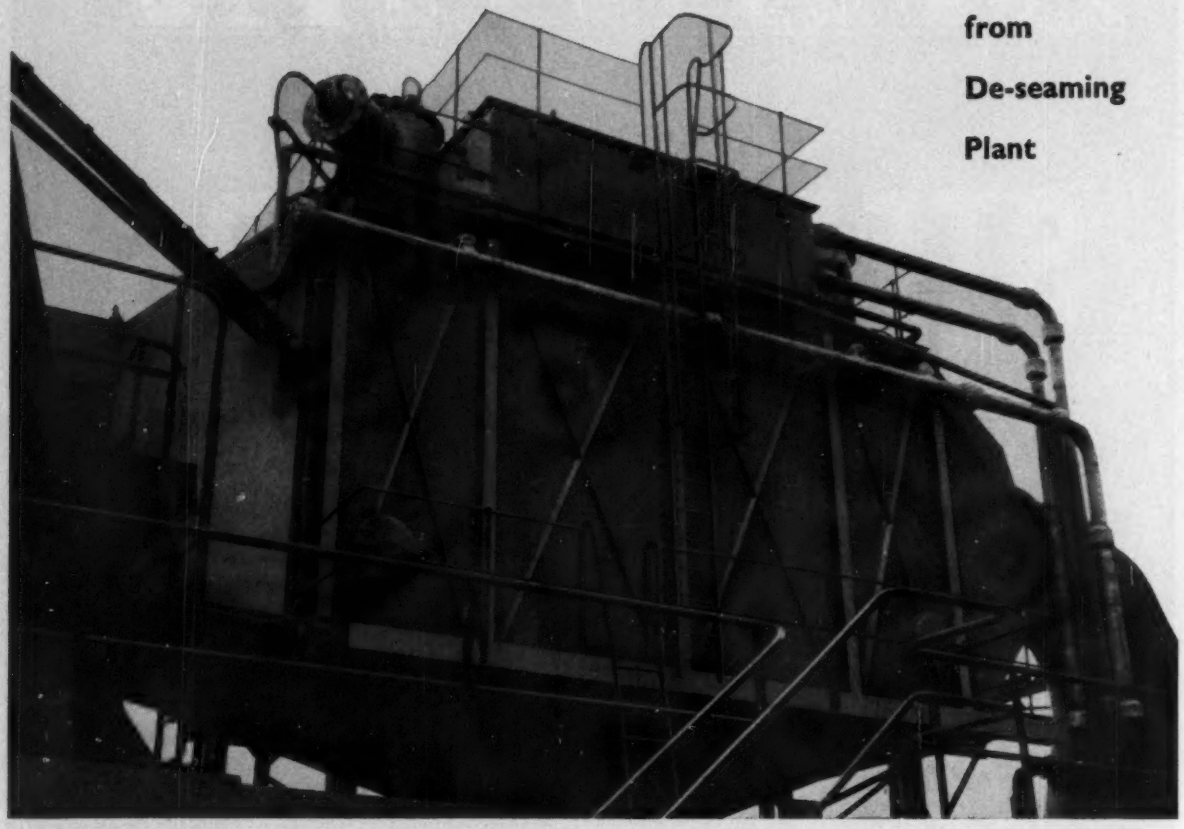
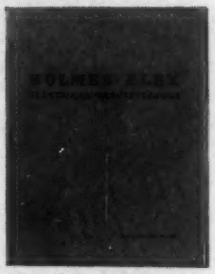
HOLMES-ELEX ELECTRICAL PRECIPITATORS

Iron oxide removal from De-seaming Plant



The Holmes-Elex Electrical Precipitator illustrated above is installed at the Corby Works of Messrs. Stewarts & Lloyds for the purpose of cleaning exhaust air from the collecting hood enclosing the De-seaming Plant. The fine particles associated with iron oxide fume, and which are responsible for the dense brown colour are removed resulting in no visible stack emission.



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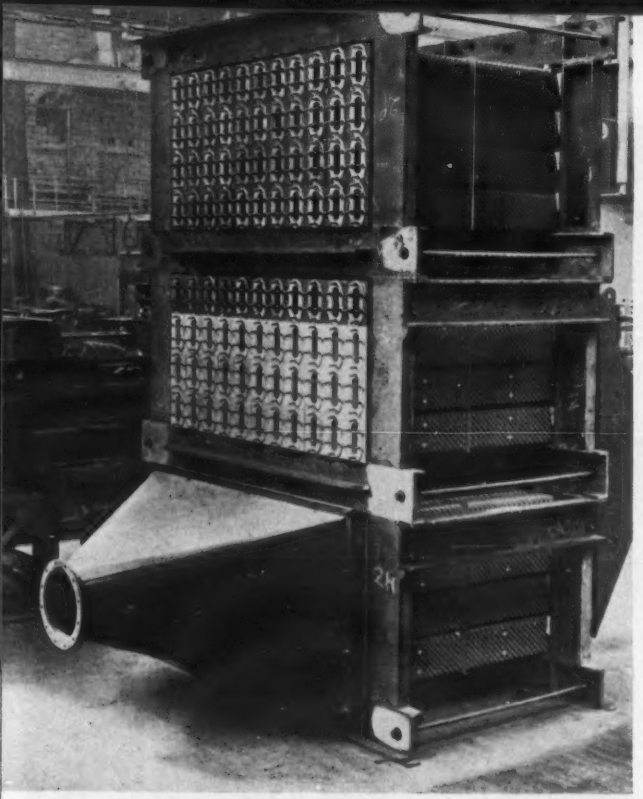

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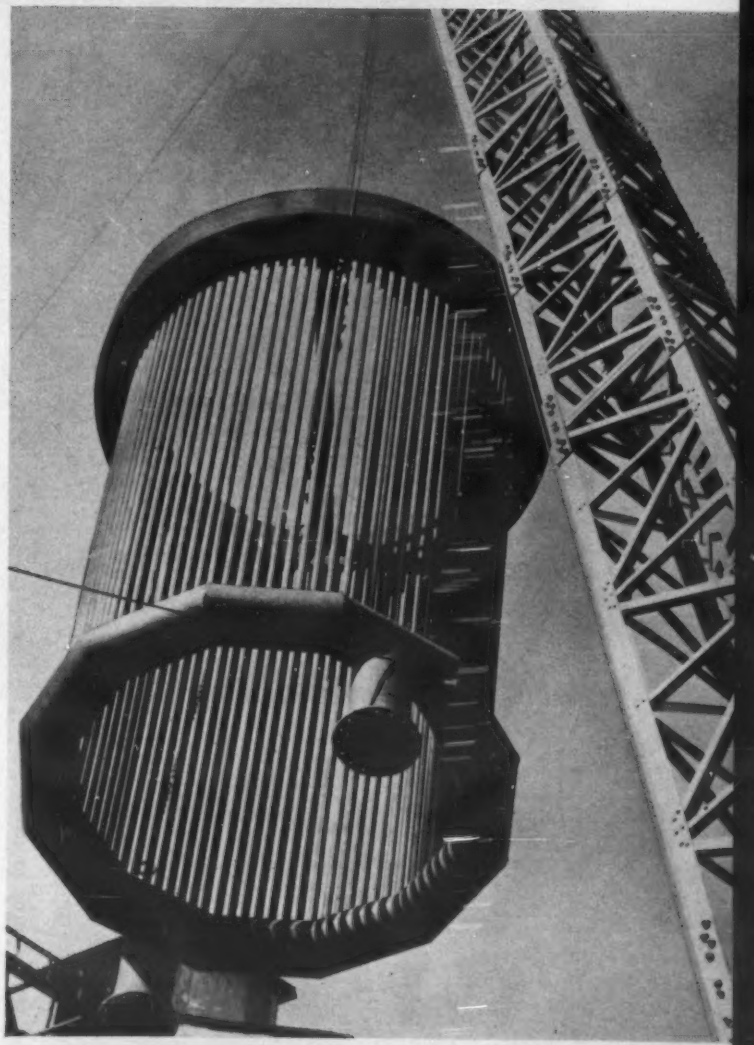
LEFT AND ABOVE LEFT: *Newton Needle type recuperators.*

RIGHT: *Inka tube bundle being lowered into position.*



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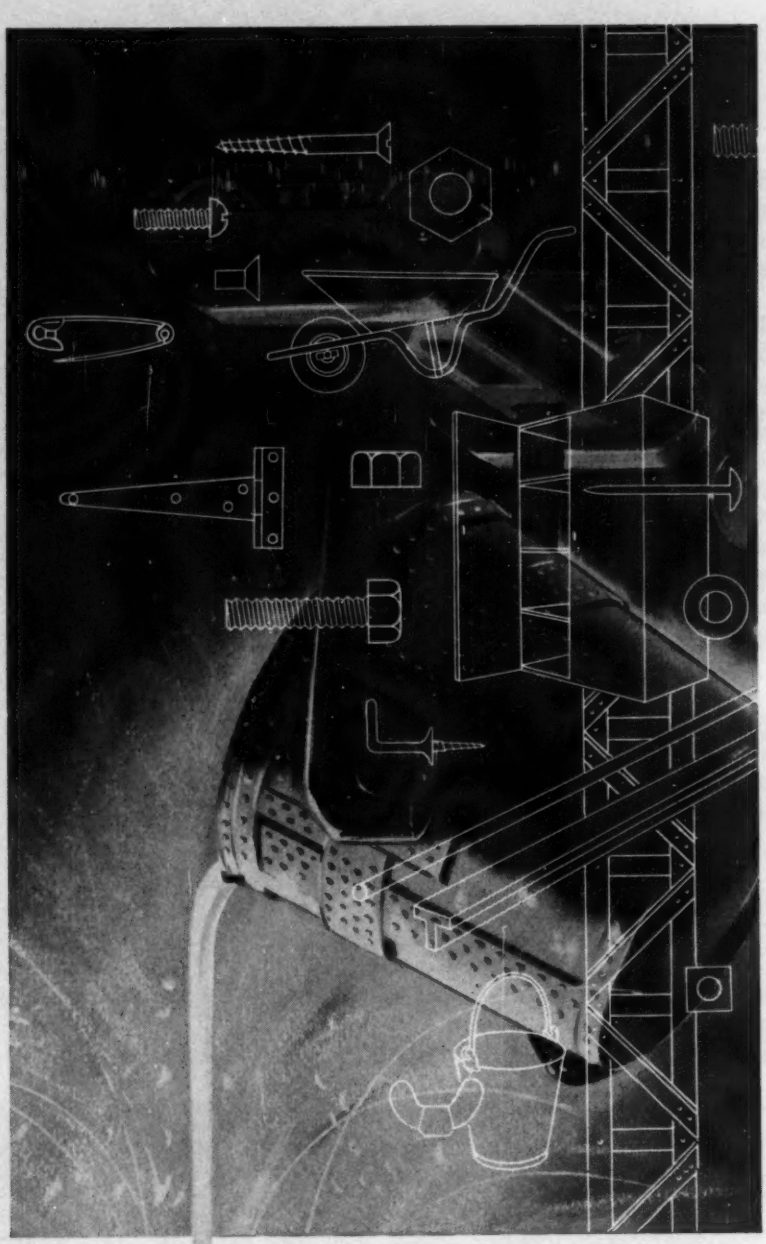

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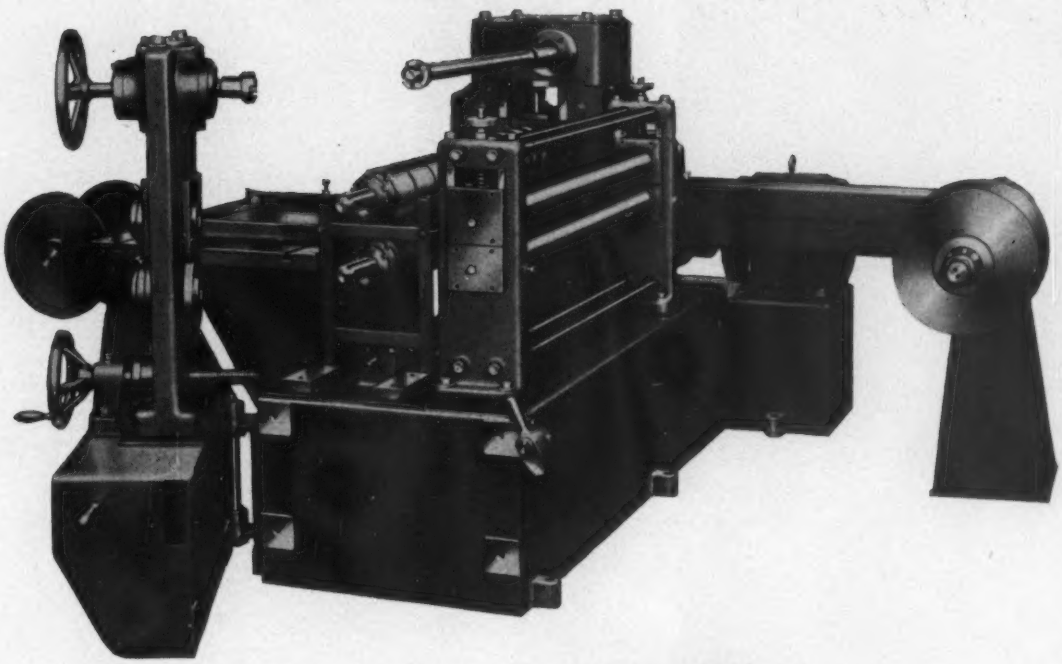

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The Shell Group started working on the problems of lubricating under radiation conditions while most nuclear power stations were still on the drawing board. In fact, Shell was the first oil company to develop Atomic Power Lubricants, and the research that went into Shell A.P.L. is characteristic of the way Shell sets about doing things. A team of research workers was assembled at Shell's Research Centre at Thornton. Series of tests were carried out both in the B.E.P.O. pile at the U.K. Atomic Energy Authority Research Establishment, Harwell, and with Thornton's own Cobalt 60 source of radiation. In 1957, after four years of research, Britain's first range of Atomic Power Lubricants was on the market.

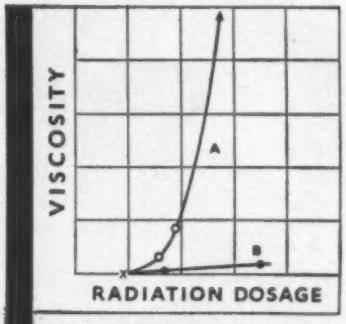
The moral of the A.P.L. story is that Shell research is supremely applicational. The Centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organisation have any major lubrication problems, it will pay you to get in touch with your local distributor of Shell Industrial Lubricants.

The Research Story

In the hundreds of complex hydrocarbons examined, very different reactions to radiation were observed according to the configuration of the atoms in the molecules. When carbon atoms were arranged in long, straight chains, radiation caused these chains to link up with one another, giving highly complex structures of an entirely different nature from the original material. The first effect of this change was to cause a rapid increase in viscosity, ultimately giving rise to a solid rubber-like product.

For example, a high quality turbine oil conforming to BSS.489 receiving a dosage of 1.77×10^{18} neutrons/cm^2 was changed into an intractable solid—a clear demonstration that radically new lubricants were needed by the nuclear industry.

Shell Atomic Power Lubricants have a molecular structure that has proved itself very resistant to radiation. In fact it will withstand a radiation dosage four million times stronger than that which will kill a man—without any significant change in structure or physical properties.



Relationship between radiation dosage and percentage increase in viscosity, cS at 100°F.
Oil A: high molecular weight long chain hydrocarbon. *Oil B:* Shell A.P.L. 731.

SHELL

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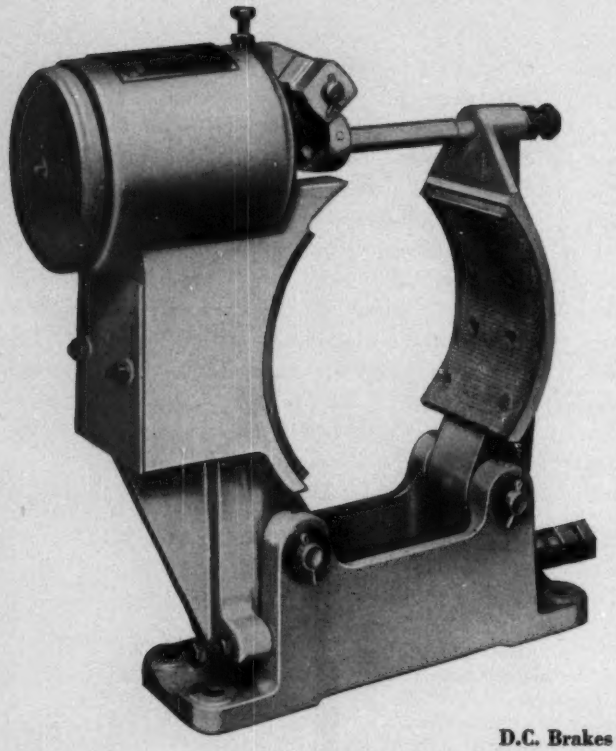

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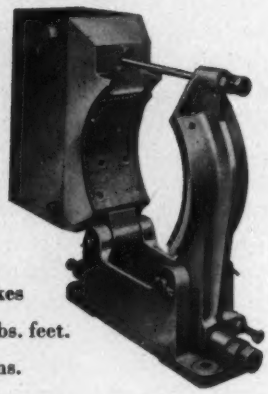

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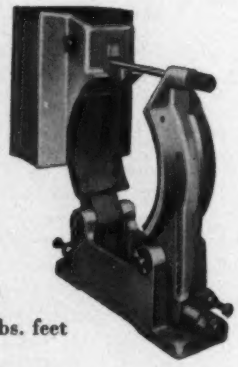

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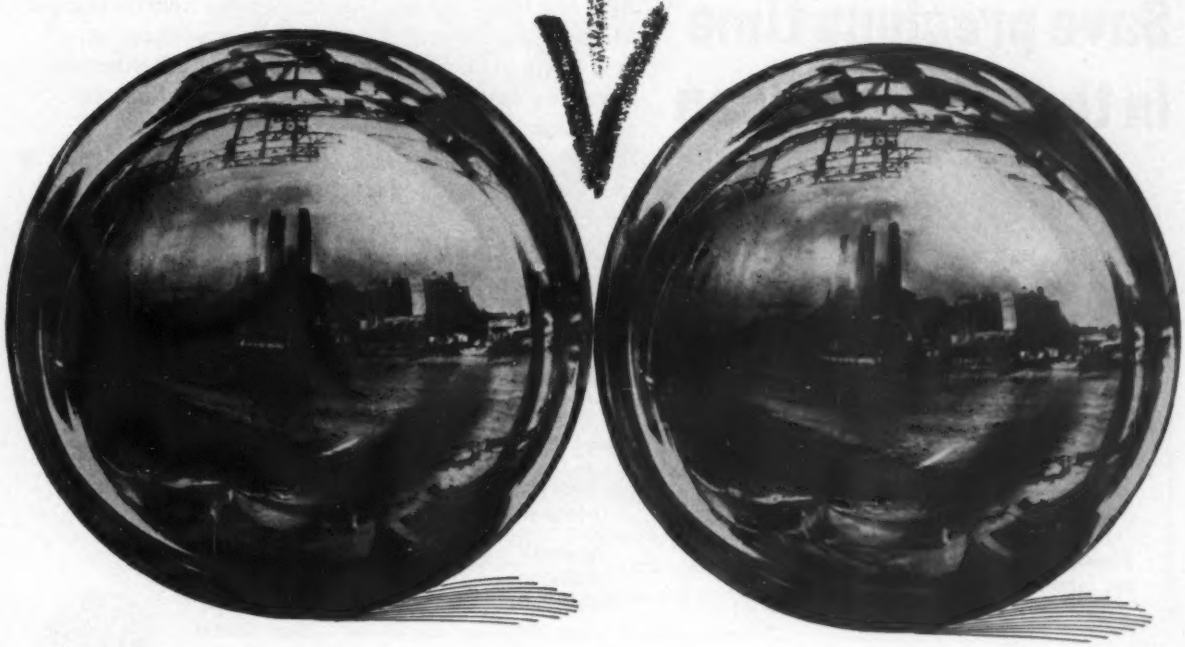

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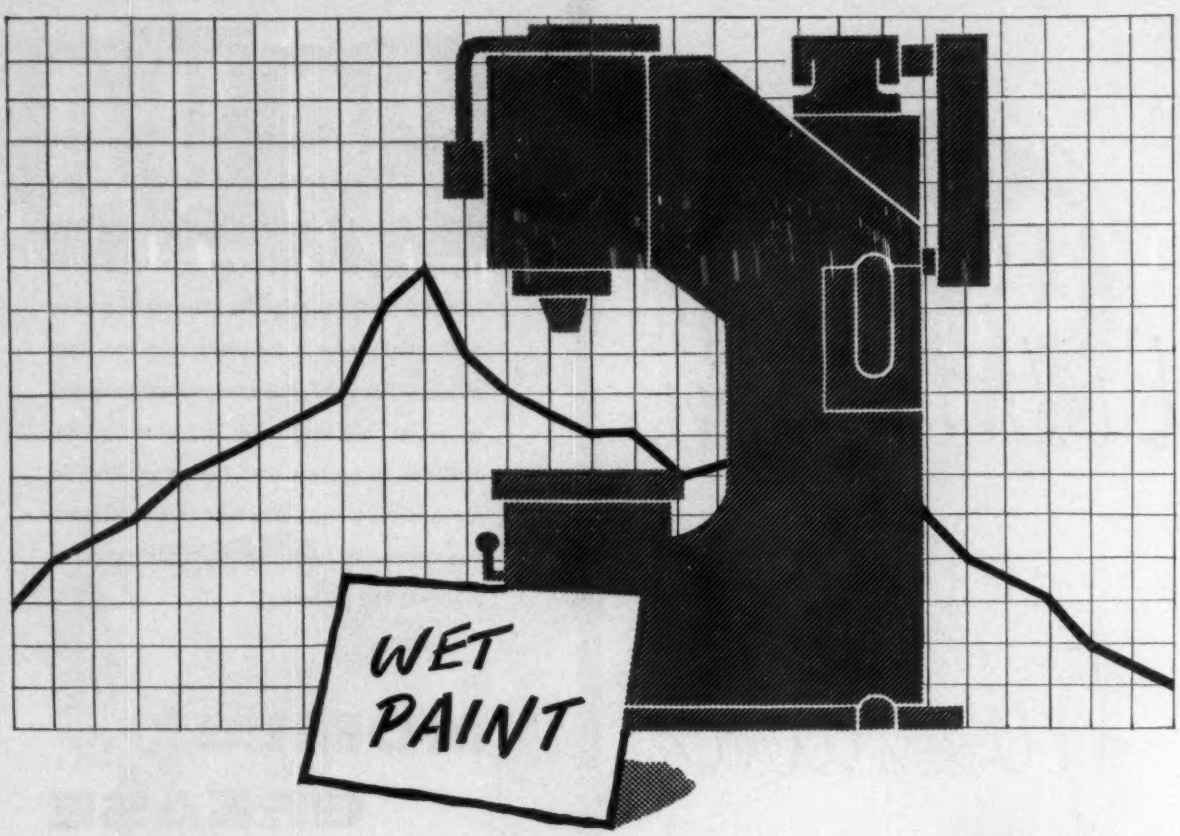

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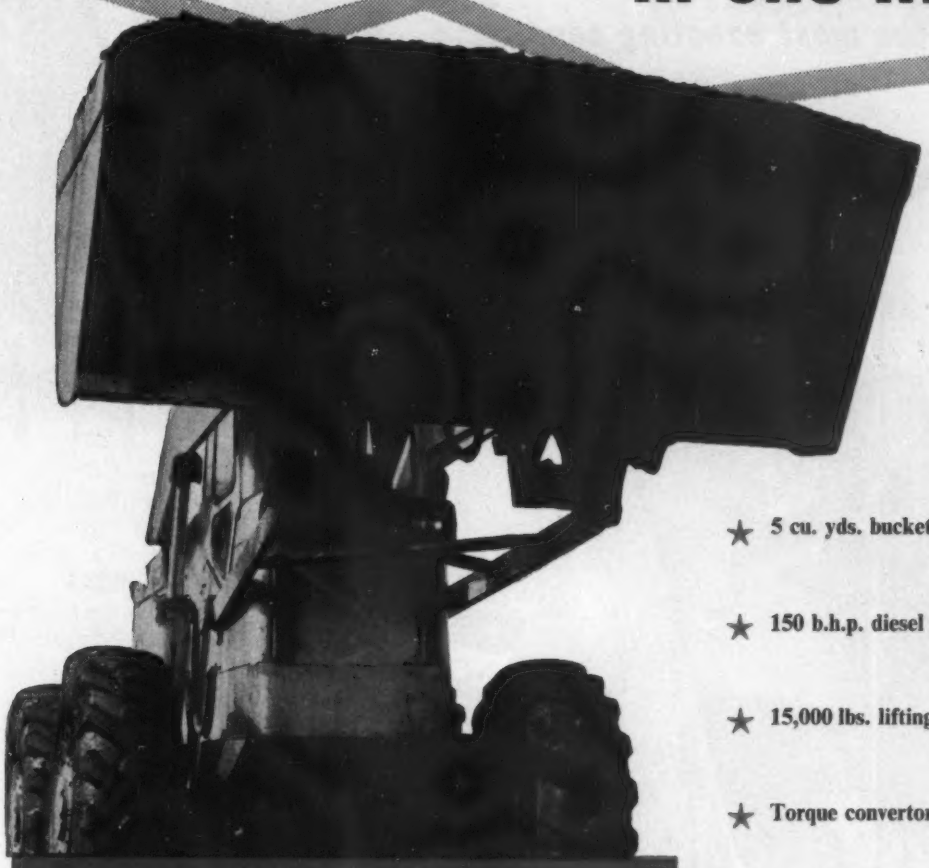

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for Hearth and Crucible of Blast Furnaces

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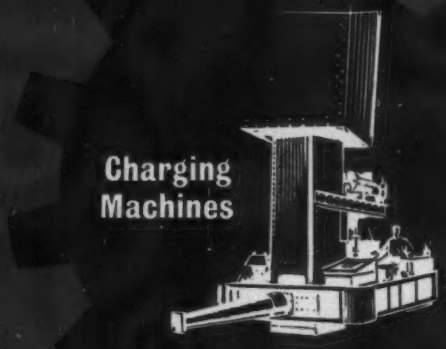
Stripping Cranes

STEELWORKS EQUIPMENT



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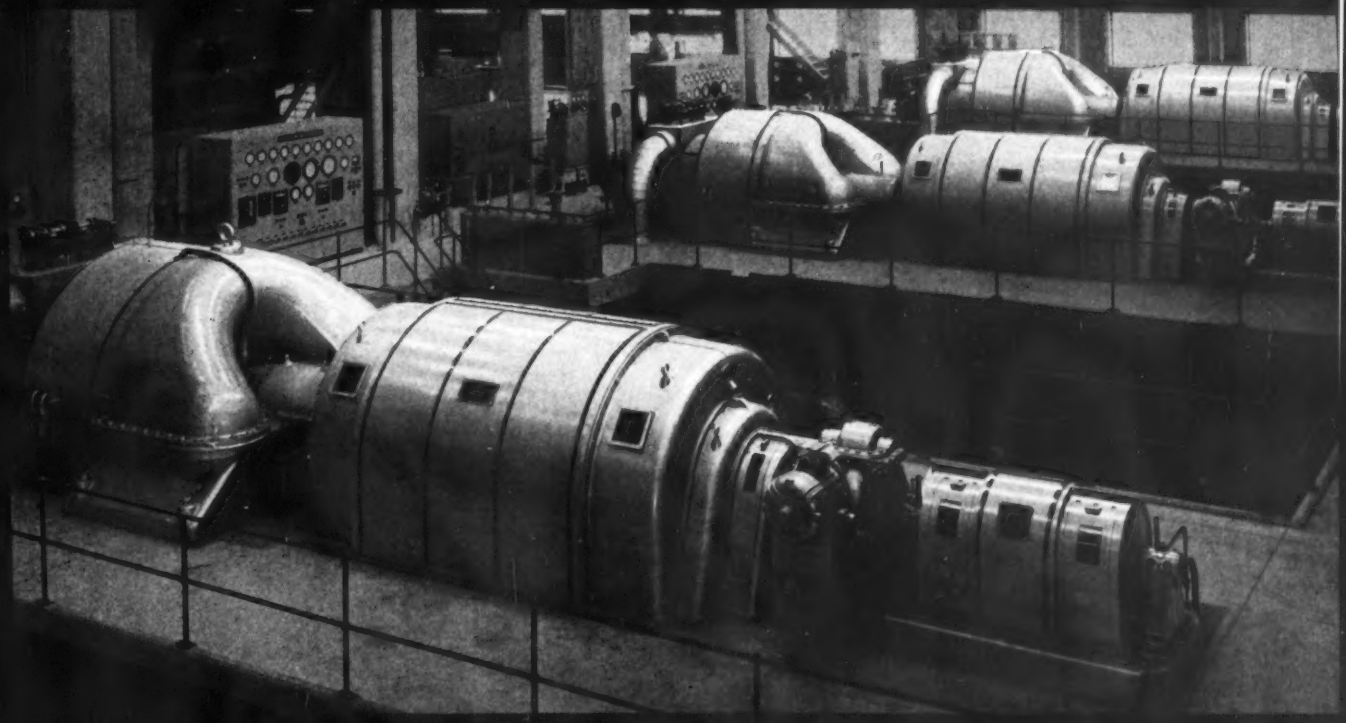
Ravenscraig, near Motherwell in Scotland, is the site of the latest and most important addition to the iron and steel industry of Scotland to which Colvilles Ltd., have already contributed so much.

Here, from an undeveloped site, the first phase of this expansion, contributing more than a thousand tons of iron daily, was put into operation within three years. In this achievement the G.E.C. assumed responsibility for the whole of the power plant. This included the civil work, cooling towers, boilers, three turbo alternators, two turbine driven blast furnace blowers, two turbine driven pumps, and all associated switchgear, transformers and ancillary equipment to control the gas, steam and electric supplies.

Electrical connection to the South of Scotland Electricity Board system and to other works of Colvilles Ltd. was also undertaken by the G.E.C.



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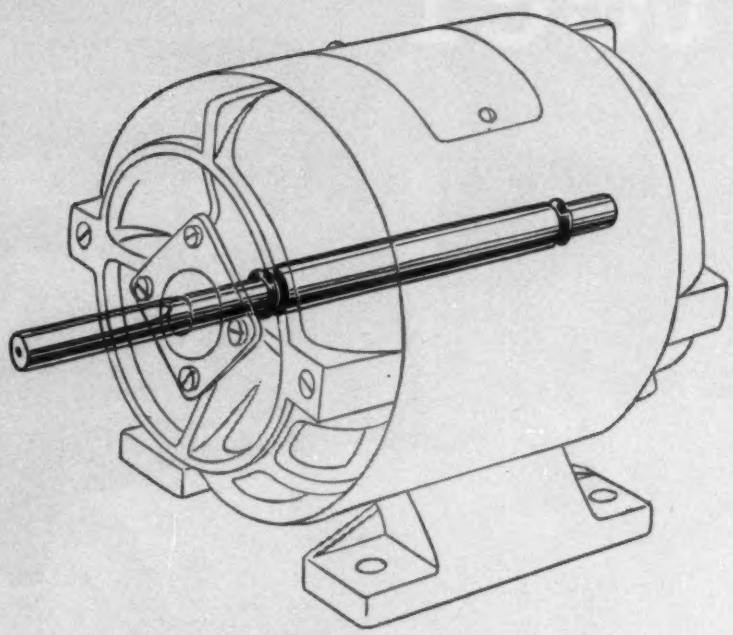

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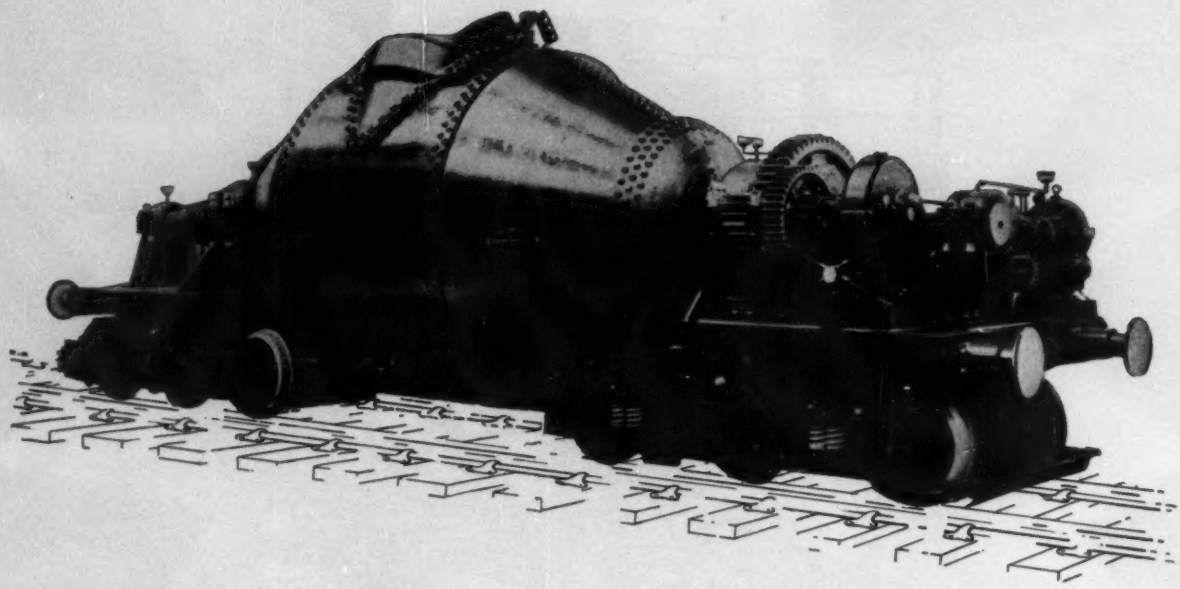

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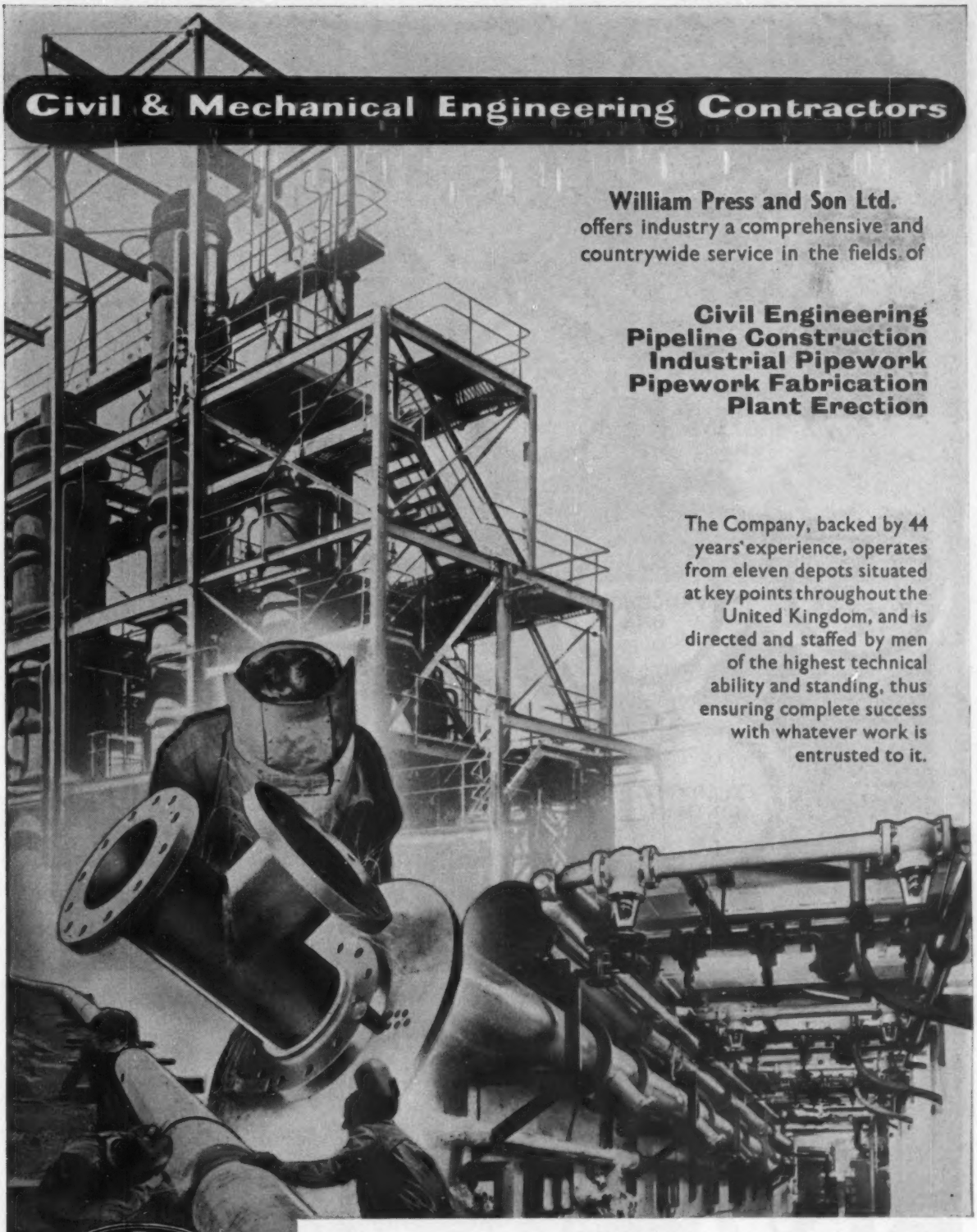

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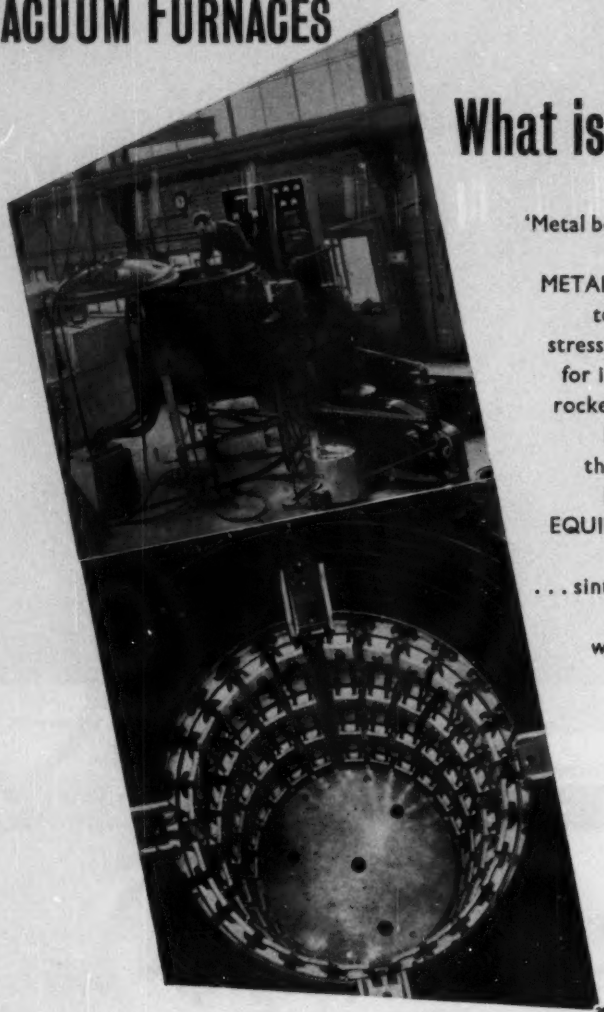

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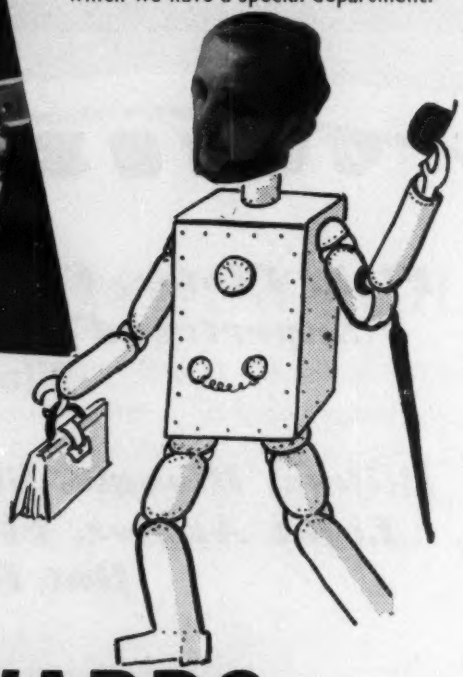
'Metal boffins' know all about the wonderful physical properties of VACUUM-METALS—high purity materials employed to withstand extreme temperatures, stresses and unusual working conditions, for instance in nuclear, jet, turbine and rocket applications. Of course, they also know a lot about EFCO-EDWARDS the people who develop and produce HIGH VACUUM METALLURGICAL EQUIPMENT of every type including . . . melting . . . casting . . . annealing . . . sintering . . . vacuum brazing furnaces . . . and non-standard furnaces for which we have a special department.



(Above) An Efco-Edwards 56 lb. vacuum melting furnace at the Rotherham laboratories of The United Steel Companies Ltd.

(Below) A close-up of the molybdenum heater of a high vacuum brazing furnace showing the concentric radiation shields.

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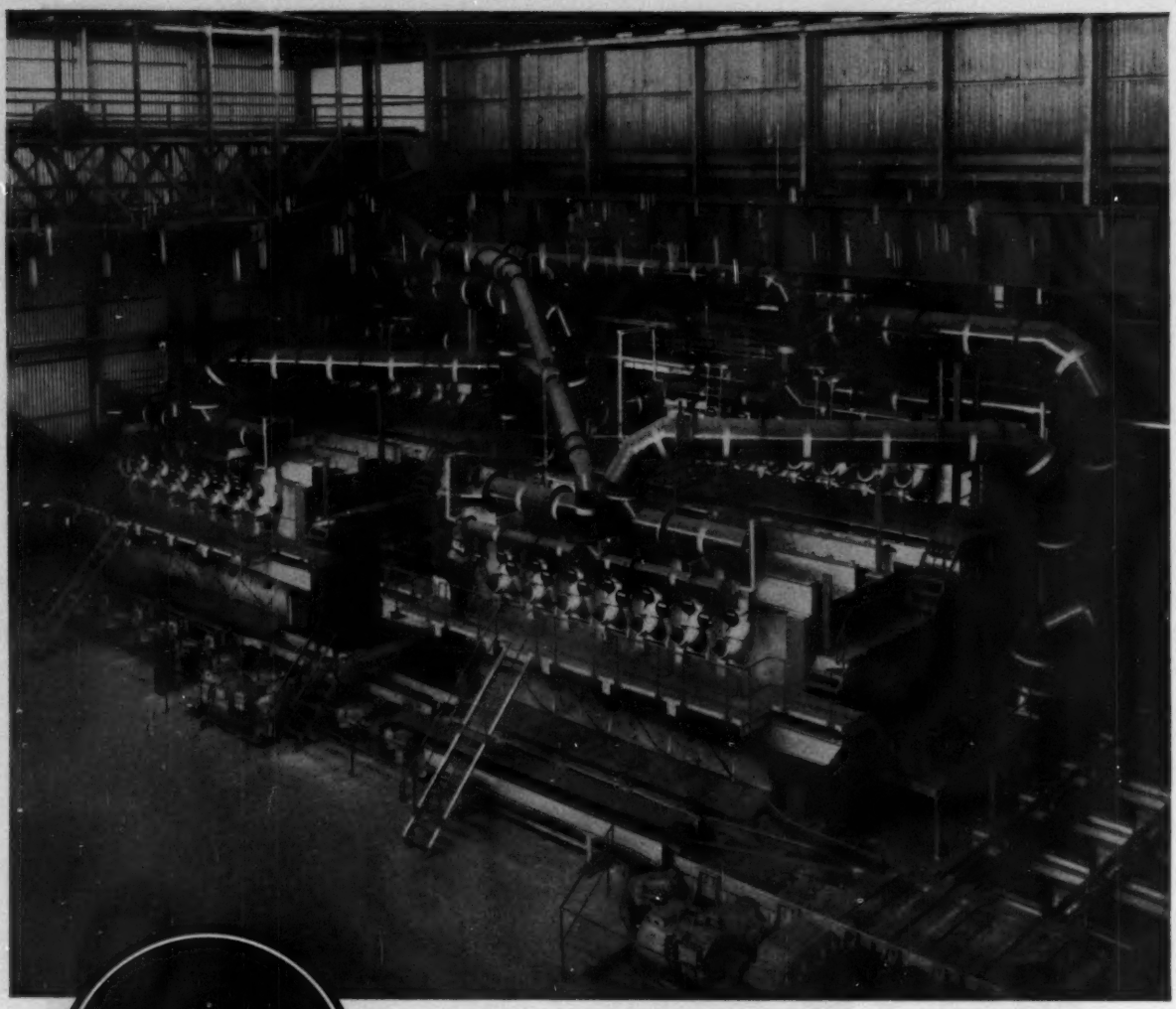

PRIEST

3 zone Bloom Re-heating Furnaces

The photograph shows two Priest 3-Zone Continuous type gas fired recuperative Bloom Re-heating Furnaces for Medium Section Mill. Installed at the Cleveland Works of Dorman Long (Steel) Limited.

We also supply similar Furnaces for re-heating slabs or blooms suitable for gas or liquid fuel firing.

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F.114

THORPE MARSH

Precipitator for world's largest boiler unit to be built by

SIMON-CARVES LTD

Removing 12 tons of dust an hour

At the new Thorpe Marsh power station, to be built for the Central Electricity Generating Board, Simon-Carves have been entrusted with the design and construction of the electro-precipitation plant which will have what is believed to be the heaviest duty yet proposed for precipitators on a single boiler unit anywhere in the world.

The unit will have an output of 550 MW and the boiler is expected to produce more than one and a half million cubic feet of flue gas per minute. The plant will remove fine dust, which would otherwise pollute the atmosphere, at a rate of about 12 tons an hour.

PREVENTING AIR POLLUTION

MW per unit	STATION	Gas volume per boiler (cubic feet per minute)
550	**THORPE MARSH**	**over 1,500,000**
120 120 100	PADIHAM 'B' DRAKELOW 'B' WILLINGTON 'A'	over 300,000
60 60 60	HAMS HALL 'C' BOLD 'B' ROGERSTONE	over 200,000
60 30 30 30	CHADDERTON 'B' FLEETWOOD HACKNEY 'B' HUNCOAT	over 100,000

This table of Simon-Carves precipitators for power stations of the Central Electricity Generating Board emphasises the magnitude of the Thorpe Marsh project. High average efficiency on plants already tested enables Simon-Carves to accept this great responsibility with complete confidence.

HIGH EFFICIENCY ELECTRO-PRECIPITATION BY

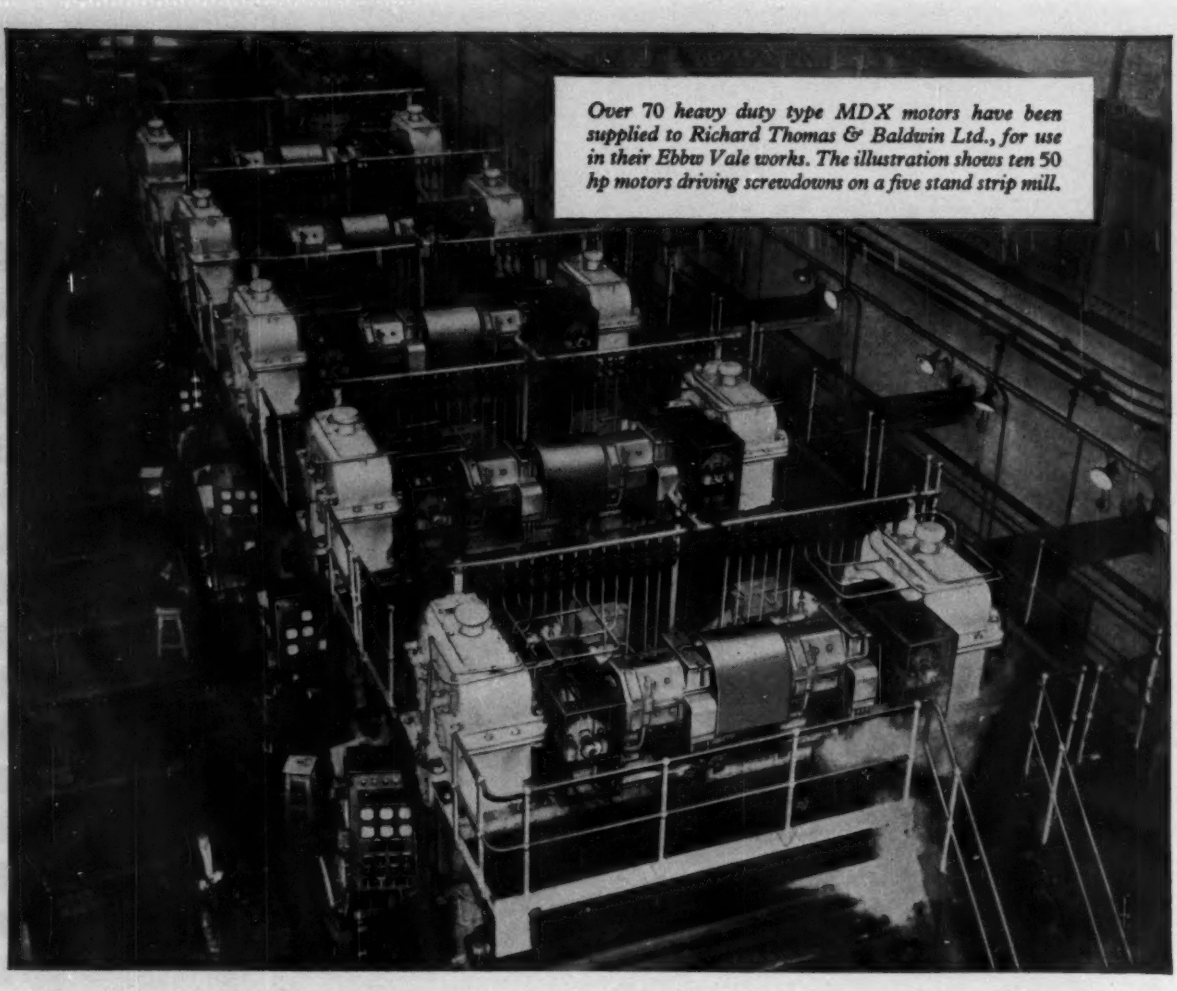
Simon-Carves Ltd

SIMON ENGINEERING GROUP

STOCKPORT, ENGLAND

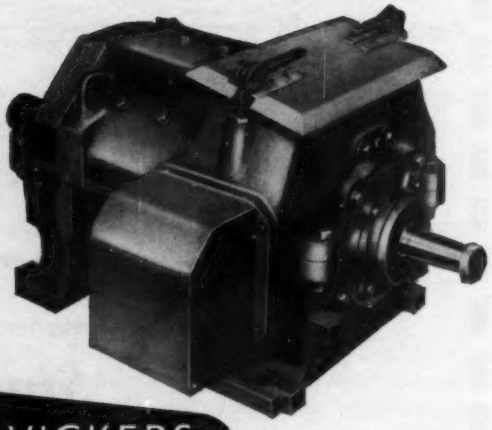
OVERSEAS COMPANIES *Simon-Carves (Africa) (Pty) Ltd: Johannesburg Simon-Carves (Australia) Pty Ltd: Botany, N.S.W.*

SC 193/PS



Over 70 heavy duty type MDX motors have been supplied to Richard Thomas & Baldwin Ltd., for use in their Ebbw Vale works. The illustration shows ten 50 hp motors driving screwdowns on a five stand strip mill.

All motors here are type MDX



Metrovick type MDX motors have been specially designed to operate under the arduous conditions of iron and steel works. Their strength and reliability, and the exceptionally low inertia of the rotating parts make these machines ideal for driving a wide range of steelworks equipment. The use of mica and glass insulation suitable for high temperature operation enables the motor to withstand heavy overloads.
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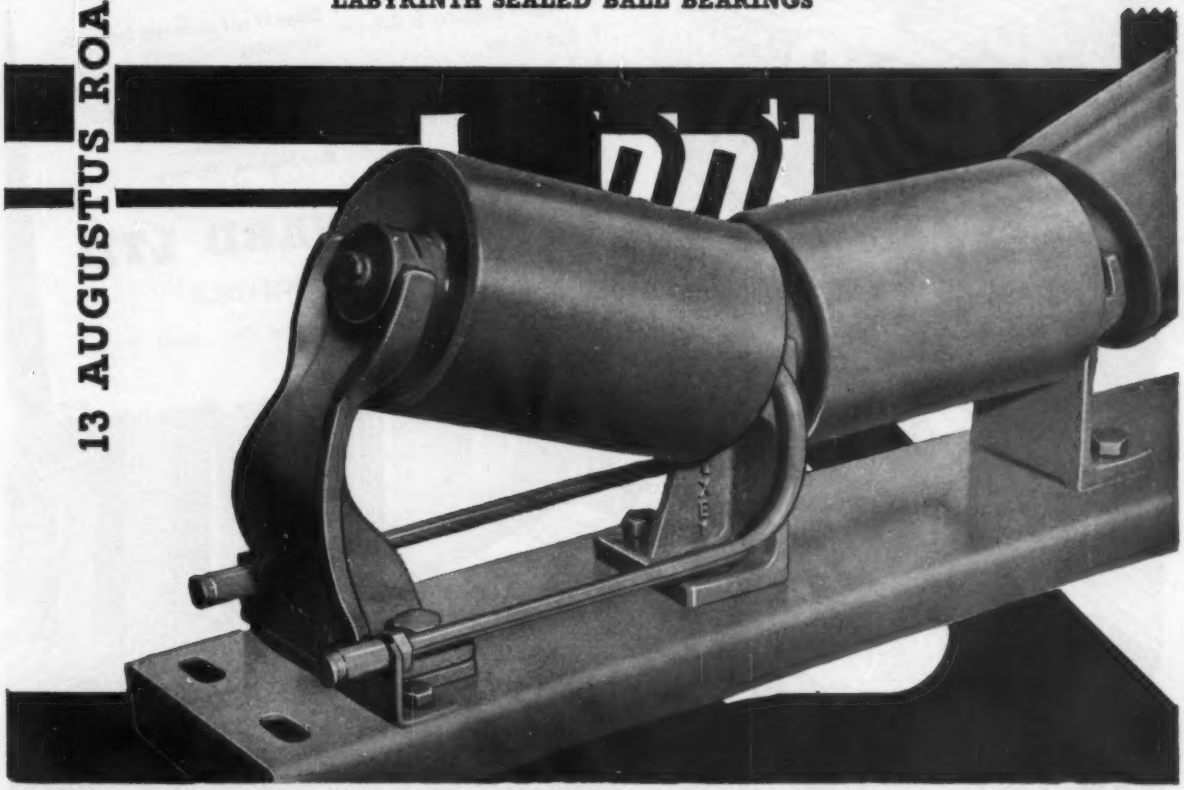

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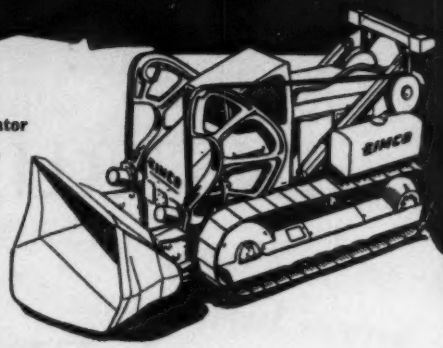
in the iron and steel industry



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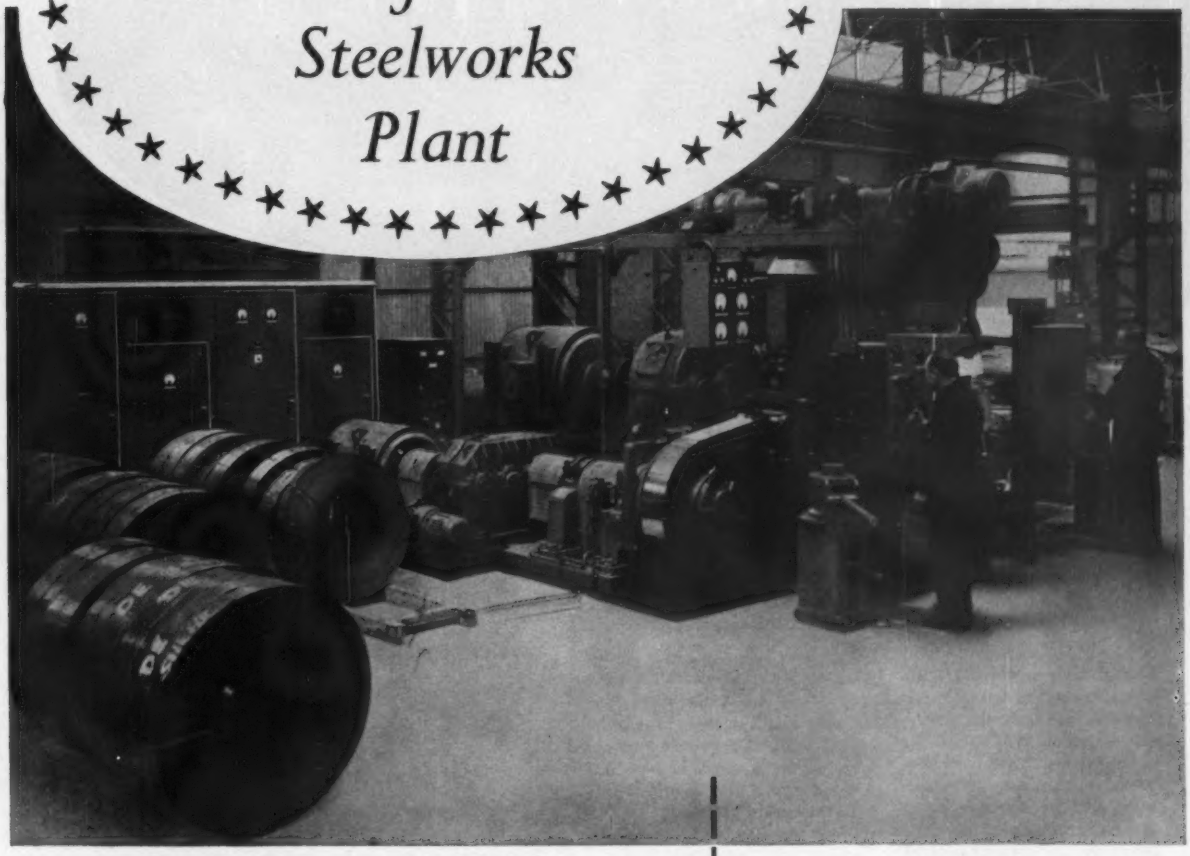
P.4172

Control Gear for Steelworks Plant



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Supplied to The English Electric Co. Ltd., Stafford, for Messrs. Graham Firth Steel Products Ltd., Walsall.

Contactor Switchgear Limited manufacture automatic electric control gear (up to 6,600v. A.C. and 650v. D.C.) for Power Station Auxiliaries, Steel Works, Water Works, Rolling Mills, Sewage Works, Chemical Plants, Gas Works and Cement Works including Cranes, Electric Furnaces, Machine Tools, Fans and Pumps.

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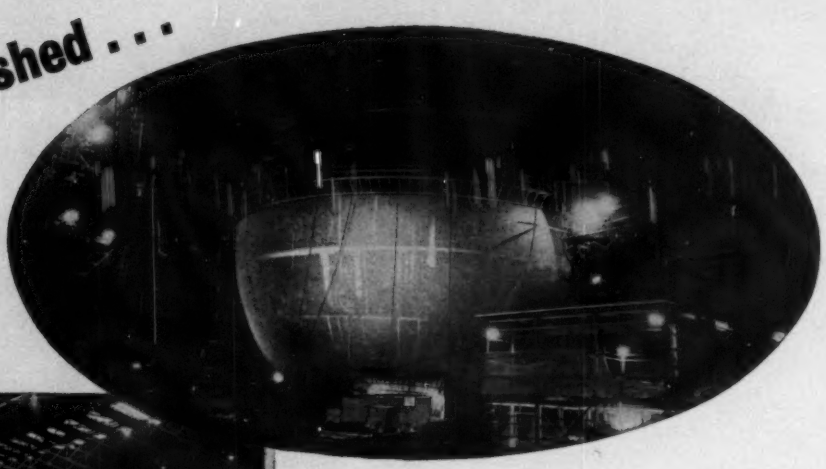

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serving every industry

The illustration shows an Igranic bar mounted contactor panel for auxiliary drives on a continuous rod and slab mill

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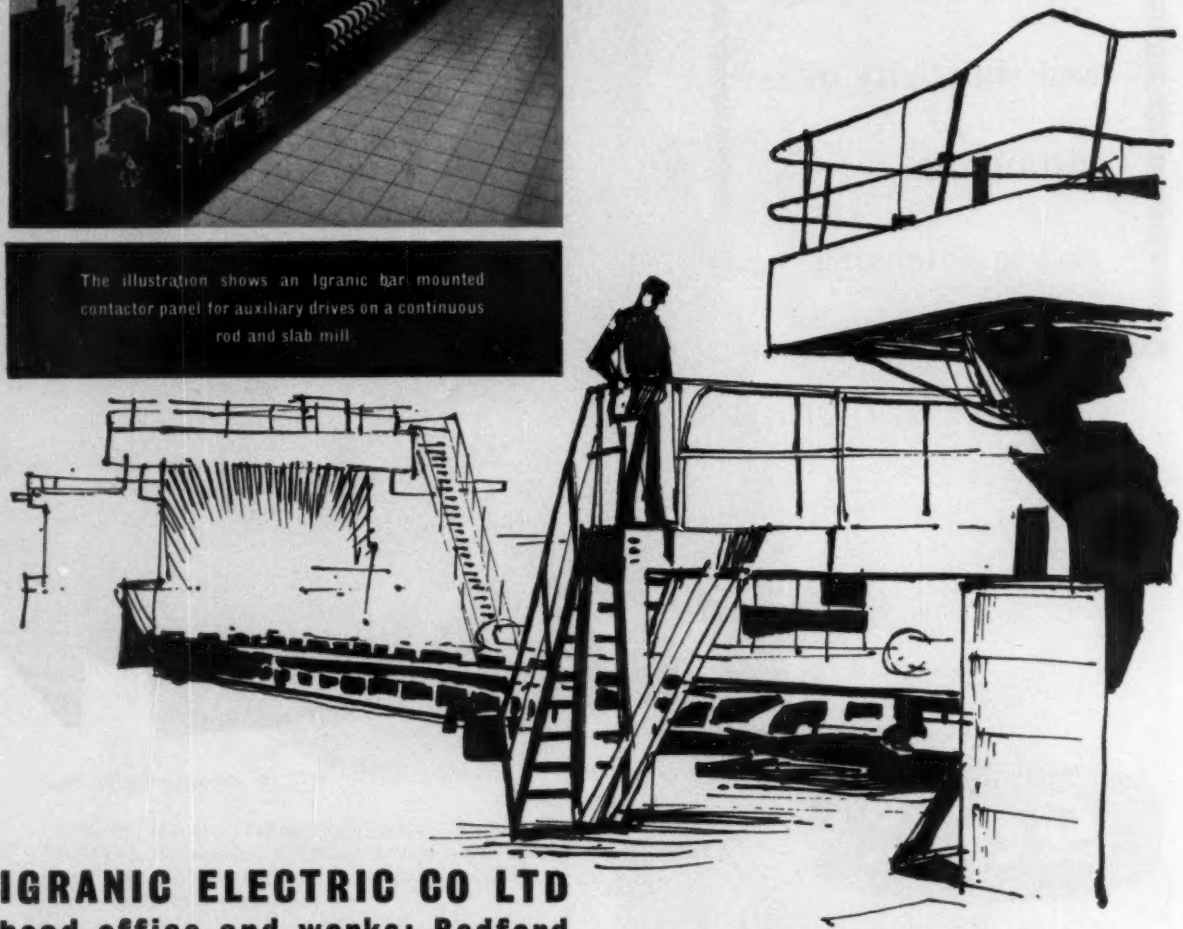

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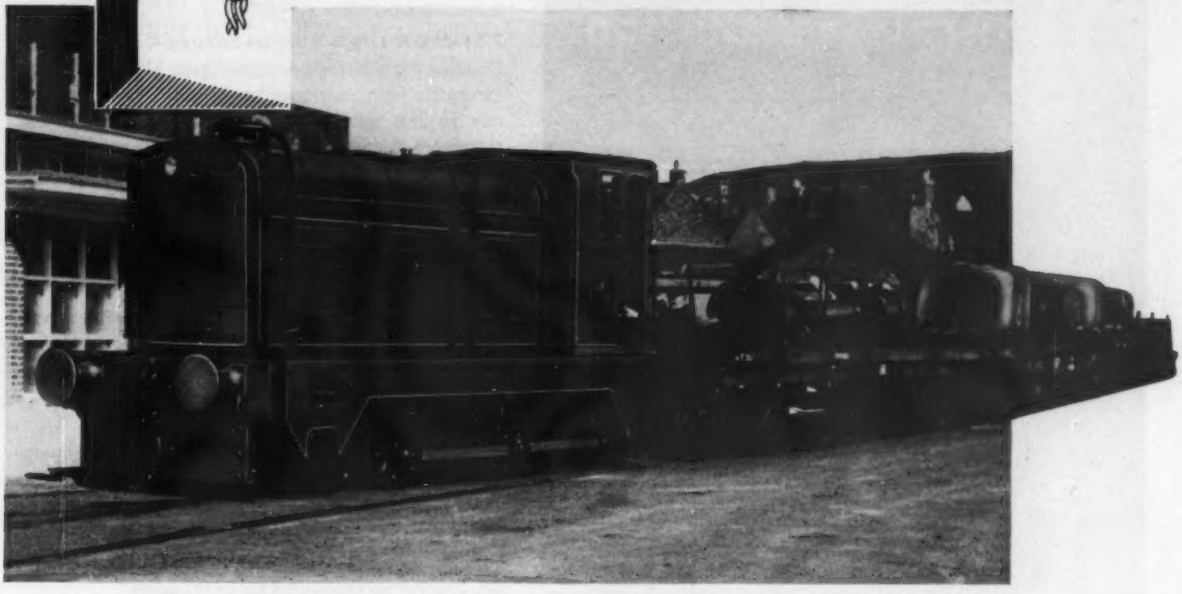

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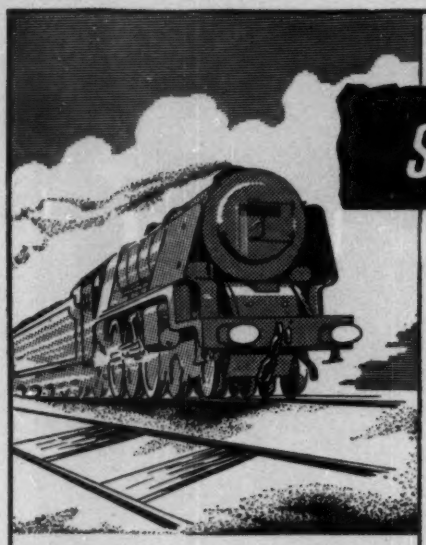

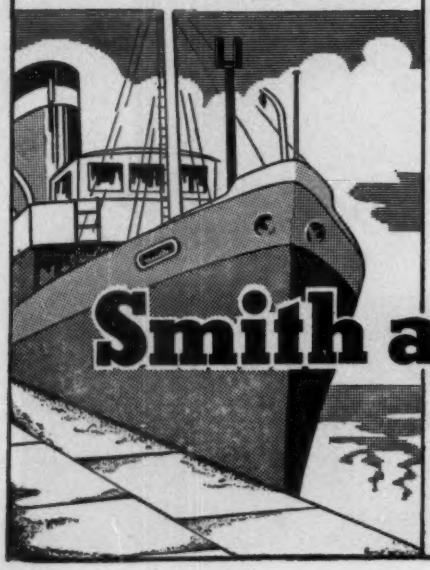

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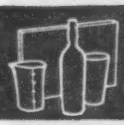
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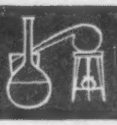
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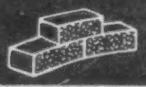
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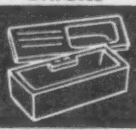
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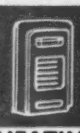
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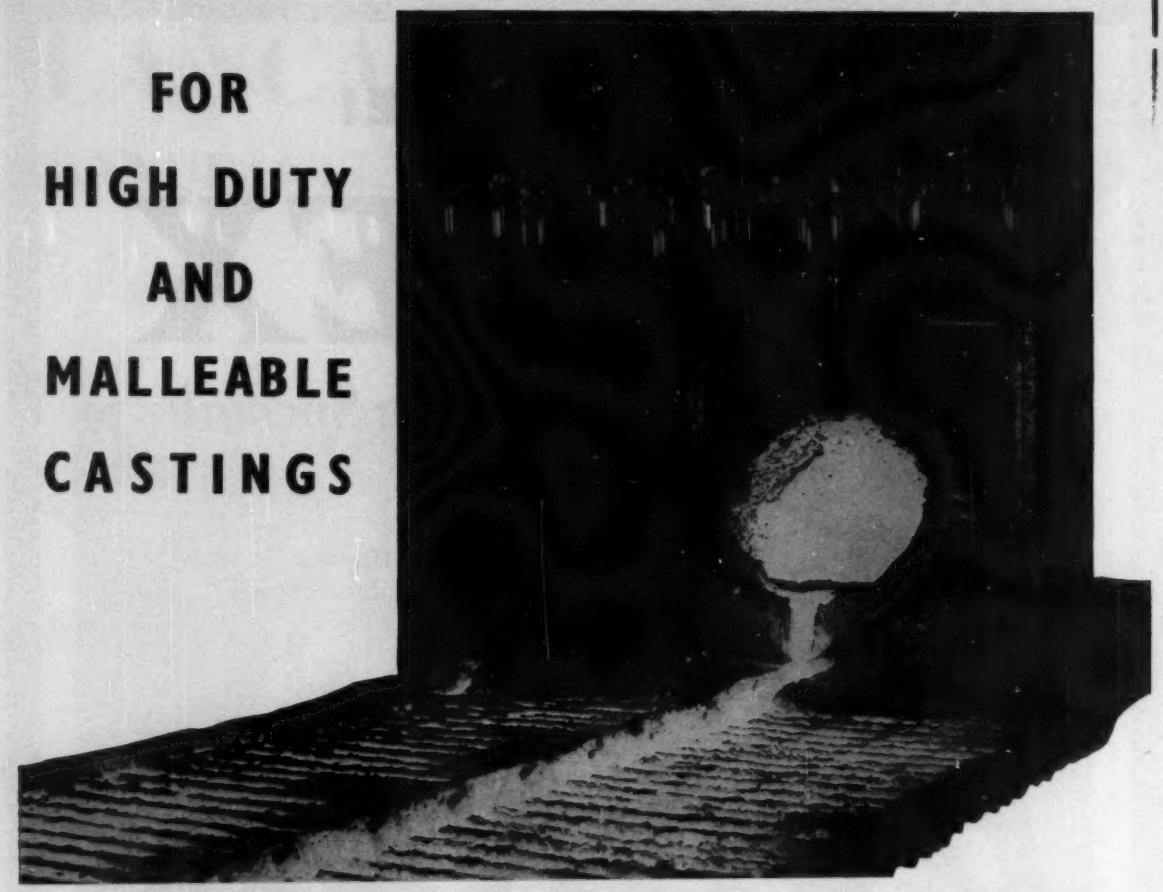

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SULPHUR %	0·06	0·07	0·08	0·05	0·08	0·07	0·06
PHOSPHORUS %	0·6–0·7	0·6–0·7	0·6–0·7	0·4–0·5	0·25	0·25	0·25
MANGANESE %	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5
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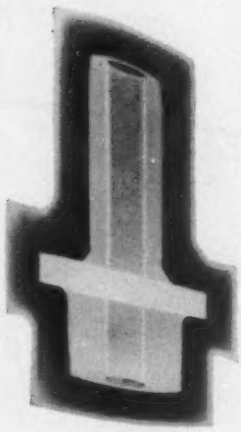

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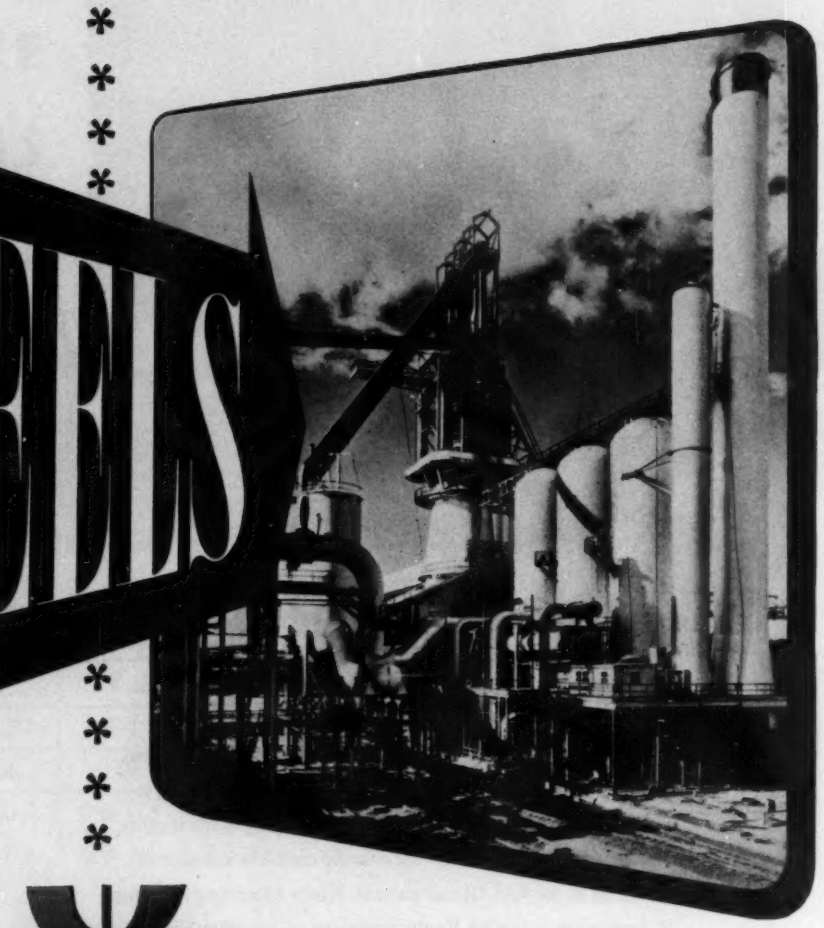

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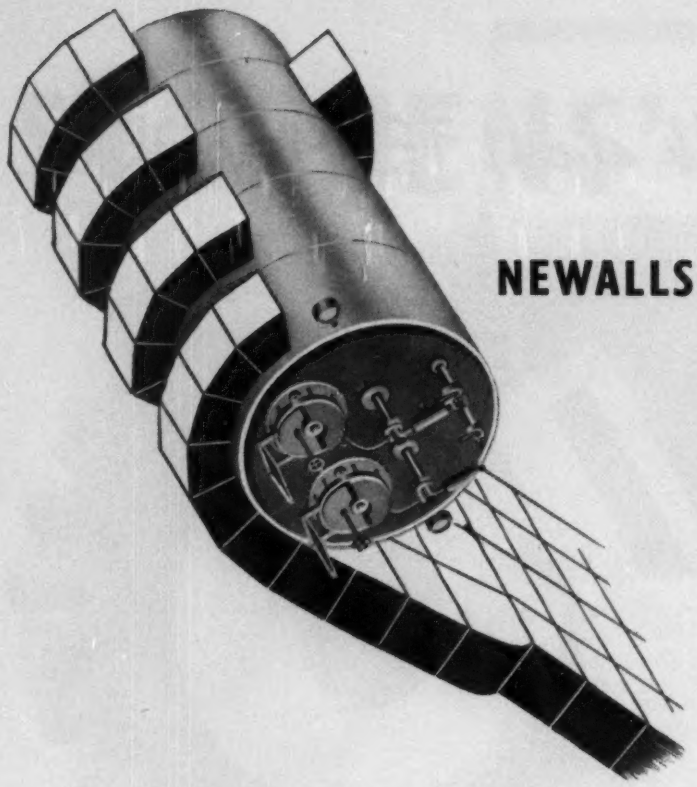

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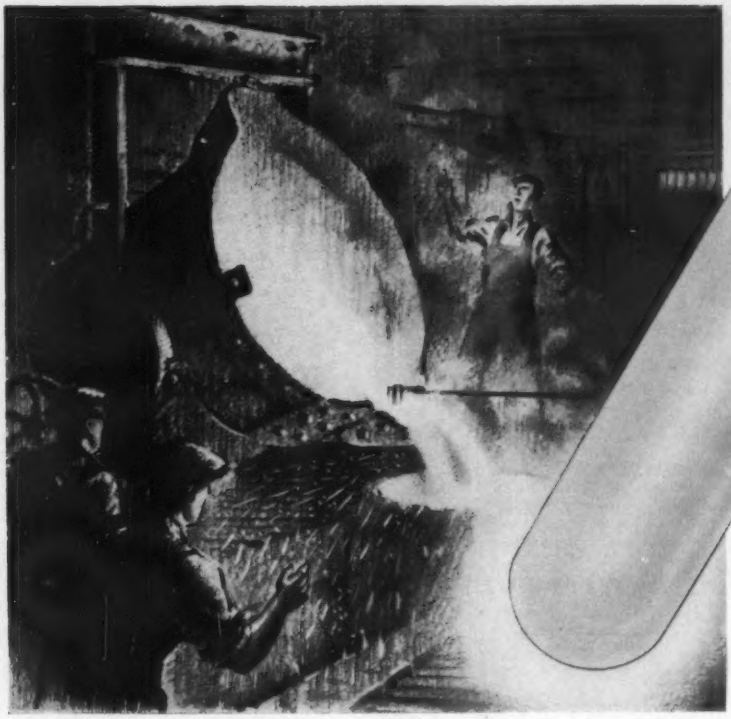

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EDITOR
K. Headlam-Morley

MANAGING EDITOR
E. R. Mort, B.SC., F.I.M.

PRODUCTION EDITOR
H. F. Cleere, B.A.

ASSISTANT EDITOR
R. J. D. Harvey, B.A.

EDITORIAL AND ADVERTISEMENT OFFICES

4 Grosvenor Gardens, London, S.W.1
SLOane 0061
Telegrams - - Irosamente, Sowest

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NOTE

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Contents

PROCEEDINGS OF THE INSTITUTE

Report of Annual General Meeting 1958 197

THE IRON AND STEEL INSTITUTE

Early Industrial Production of Bessemer Steel at Edsken *by P. Carlberg* 201

Basic Open-hearth Steelmaking in the U.S.A. *by M. W. Lightner and D. L. McBride* 205

A Study of the Distortion of High-carbon High-chromium Die Steels *by K. Sachs* 216

Criterion for Peritectic and Eutectic Reactions *by M. Hillert* 224

A Programme-controlled Reduction Test for Blast-furnace Burdens *by R. Linder* 233

Conditions for Stability of Graphite, Iron, and Its Oxides and Carbides *by D. I. Cameron* 251

LETTER TO THE EDITOR

Impact Properties of High-purity Nickel–Chromium–Molybdenum Steels *by J. M. Capus and G. Mayer* 255

CORRESPONDENCE ON PAPERS

Correspondence on Hot-topping 263

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Determination of Boron in Carbon and Low-alloy Steels *by the Methods of Analysis Committee* 227

The Constitution of Alloys of Iron with Ruthenium, Rhodium, Palladium, and Silver *by W. S. Gibson and W. Hume-Rothery* 243

Solubility and Diffusion of Carbon in a Silicon–Iron Alloy *by D. A. Leak and G. M. Leak* 256

NEWS 269 **ABSTRACTS** 273

TRANSLATIONS 272

THE IRON AND STEEL INSTITUTE, 4 GROSVENOR GARDENS, LONDON, S.W.1

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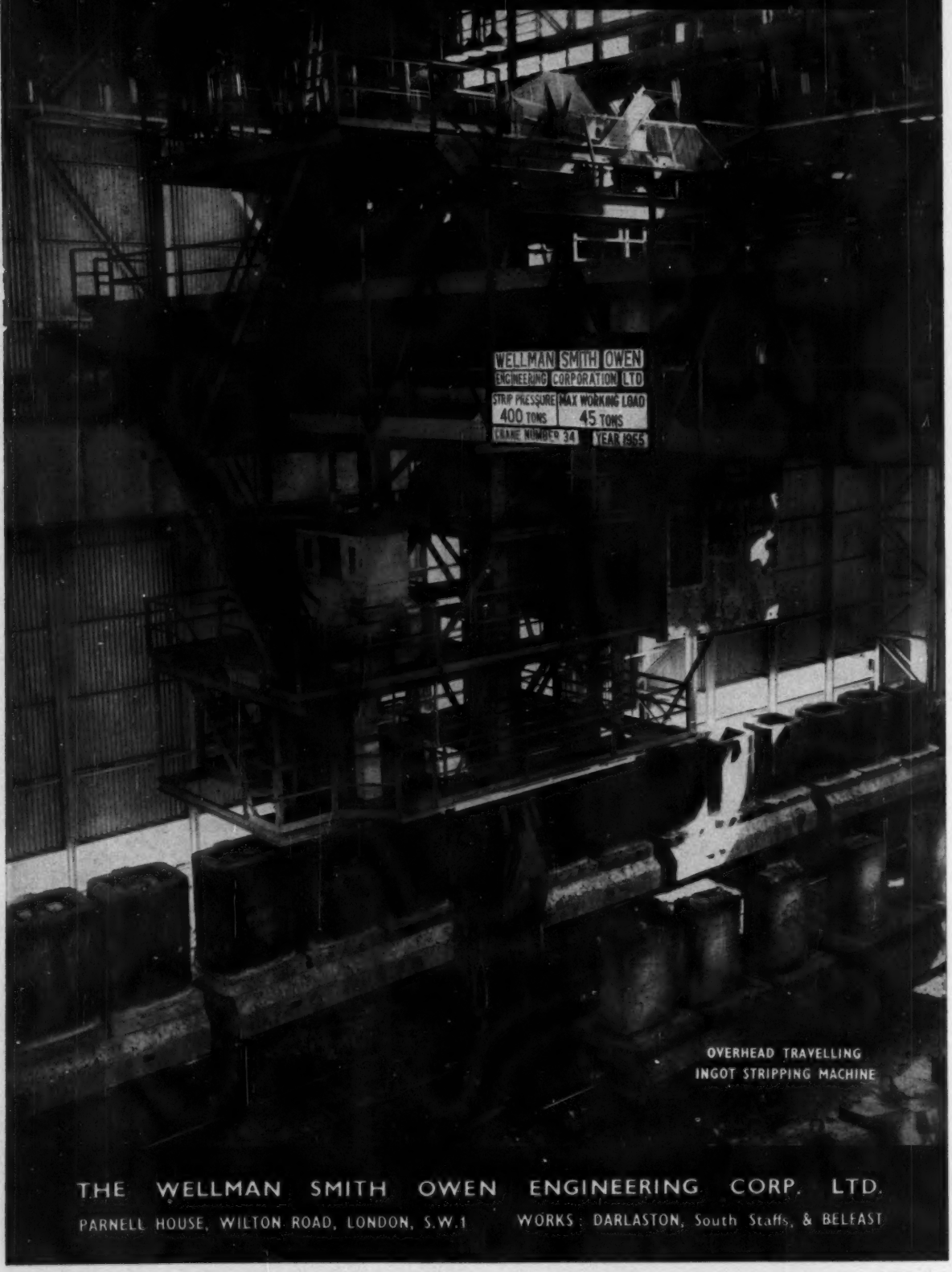

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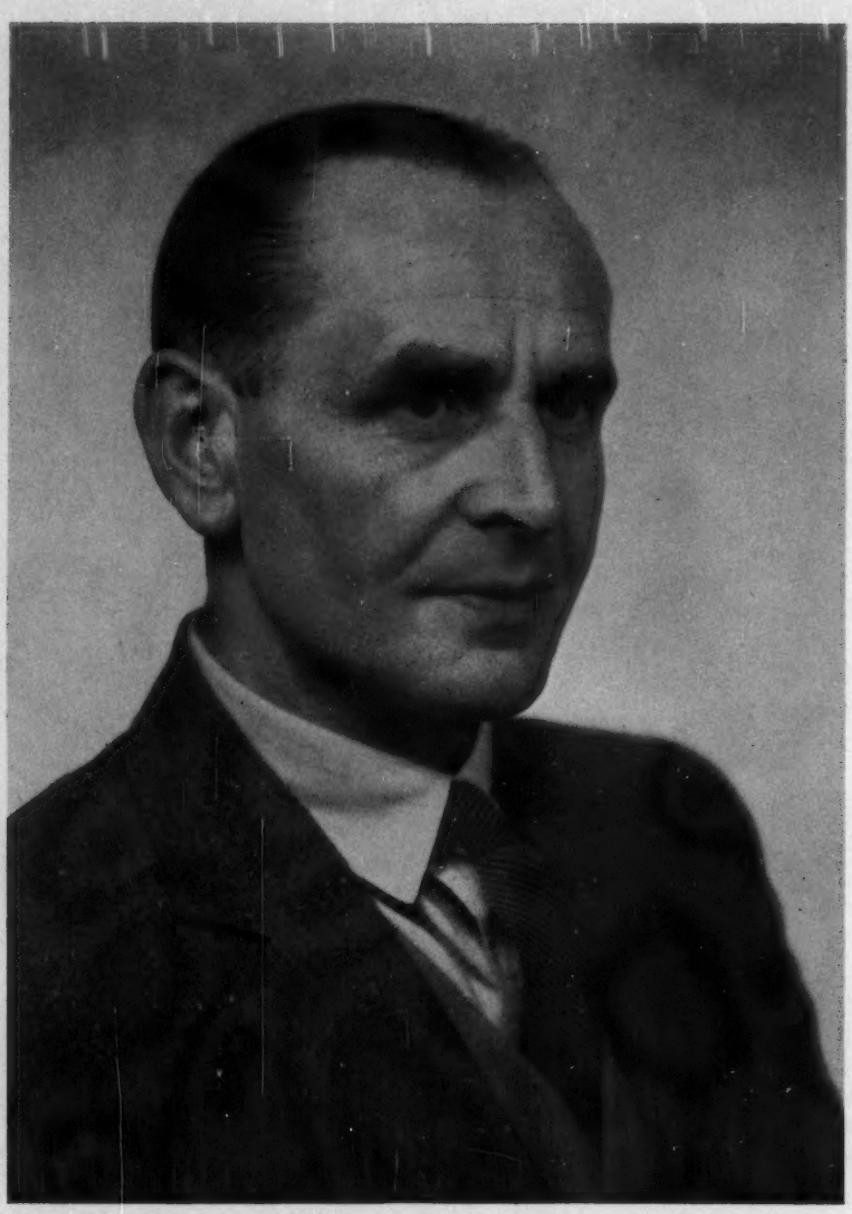
G. PARKIN, A.Met., F.R.I.C., F.I.M.

GEORGE PARKIN was born in Sheffield and attended the former Central Secondary School. He started work in the laboratories and electric steel department of Spear and Jackson Ltd., from whence he moved to the Research Department of Brown Bayley Steels Ltd. He later spent two years at Edward Pryor and Son, Ltd., subsequently returning to Brown Bayley Steels Ltd. In 1946 he was appointed Chief Metallurgist, and in 1953 Director of Research and Development at J. B. & S. Lees Ltd., West Bromwich. Early this year Mr. Parkin returned to his native city, on his appointment as Manager of the newly established Production Development Division of the Mappin and Webb group of Companies.

Mr. Parkin continued his education at the University of Sheffield, where he obtained the Associateship in Metallurgy. Further studies led to the Associateship and subsequently Fellowship of the Royal Institute of Chemistry. He was elected a Member of The Iron and Steel Institute in 1940, and a Fellow of The Institution of Metallurgists in 1946. He is a member of other professional and technical bodies, including the American Society of Metals.

Mr. Parkin was for several years Honorary Secretary to the then Sheffield section of the Royal Institute of Chemistry, and later became Proceedings Secretary to the Sheffield Metallurgical Association, of which he is a Sorby Prizewinner. He has presented papers on various metallurgical subjects, and has been keenly interested for more than twenty-five years in the work of the National Trades Technical Societies, of which he is a Freeman and a National Vice-President.

Mr. Parkin was elected President of the Birmingham Metallurgical Society for the Golden Jubilee Year, 1953, which was marked by a symposium, a civic reception, and the issue of a special Jubilee edition of the Society's *Journal*. Last year Mr. Parkin was elected President of the Staffordshire Iron and Steel Institute, and as such he served as an Honorary Member of Council of the Iron and Steel Institute during his term of office.



G. Parkin, A.Met., F.R.I.C., F.I.M.
Honorary Member of Council, 1957–1958

PROCEEDINGS OF THE INSTITUTE

Reports of Council · Meetings · Notices

Annual General Meeting, 1958

The EIGHTY-NINTH ANNUAL GENERAL MEETING of THE IRON AND STEEL INSTITUTE was held on Wednesday and Thursday, 7th and 8th May, 1958, at the Offices of the Institute, 4 Grosvenor Gardens, London S.W.1. Mr. A. H. INGEN-HOUSZ, the Retiring President, was in the Chair at the beginning of the Meeting, his place being taken later by Mr. C. R. WHEELER, C.B.E., the new President.

Sessions were held at 2.45 P.M. on the Wednesday and at 10 A.M. and 2.30 P.M. on the Thursday. On the Wednesday evening a Dinner for Members was held at Grosvenor House, Park Lane, London W.1, attended by about 1500 Members and guests.

MINUTES OF PREVIOUS MEETING

THE MINUTES of the previous Meeting were taken as read, and were confirmed and signed.

WELCOME TO MEMBERS AND VISITORS

The **President**, on behalf of the Council, offered a cordial welcome to all the Members and guests attending the Meeting, and especially to those from overseas. He was especially glad to see Monsieur P. van der Rest, President of the Groupement des Hauts Fourneaux et Aciéries Belges, who would be their host at the forthcoming Special Meeting.

OBITUARY

The Institute had lost a number of Members through death during the year; the President referred in particular to Lord Airedale of Gledhow, who had joined the Institute in 1906 and, after serving as a Member of Council and as a Vice-President, had been elected an Honorary Vice-President in 1937.

PRESENTATION OF REPORT OF COUNCIL AND ACCOUNTS

The **President** then presented the Report of Council for 1957 and the Statement of Accounts (*J.I.S.I.*, 1958, vol. 189, May, pp. 1–11) and moved their adoption.

There were certain criteria, he said, by which it was possible to judge the prosperity and progress of an Institute such as theirs; these included financial stability, membership, publications, and the extent and usefulness of the activities carried out on behalf of the members and the industry in which they were engaged.

So far as the first point was concerned, the Honorary Treasurer would have little difficulty in showing that the financial position was reasonably satisfactory.

With regard to the second point, the total number of members at the end of 1957 had been nearly 100 less than the year before, but this was believed to be due to a combination of special causes. The Council did not expect a reversal of, or a lengthy check in, the upward trend which had been so strong since the war.

On the third point, the Council gave constant care to maintaining and improving the quality of the *Journal*. They were encouraged to believe that those efforts were not unsuccessful by the kind things said about the *Journal* by friends in many countries, as well as by the rapid growth in sales. Their thanks were due to the Publication Committee and its able Chairman, Mr. D. A. Oliver, C.B.E.

On the fourth point the President said that they were endeavouring to maintain and improve the activities and services provided for Members.

The Report of Council referred briefly to the meetings held during the past year; in that connection he congratulated in particular the Engineers Group on maintaining their high standard, and also the Powder Metallurgy Group, which had been started jointly with The Institute of Metals, on the success of its first meetings, which gave ground for confidence that it would grow from strength to strength.

The Library and Information Service was being reorganized, and they wished well to their new Librarian, Mr. M. L. Pearl. The Co-operative Translation Service had made a good start. The experience of the first year's operation made it reasonable to anticipate that the service would prove of lasting value.

The Institute valued the co-operation it had received from many other societies in the U.K. and all over the world. The help which it obtained from the Affiliated Local Societies was most valuable. During the year the East Midlands Metallurgical Society had become affiliated, and they looked forward to many years of happy association. The Brazilian Association for Metals and the Argentine Institute of Metals had accepted invitations to become kindred societies, which now numbered 20. There was a great future for the steel industry in Latin America, and the Council trusted that the reciprocal arrangements would be of mutual value.

The "History of the British Iron and Steel Industry, 450 B.C. to A.D. 1775," by Dr. H. R. Schubert, the Institute's Historical Investigator, had been published at the end of 1957; it was a magnificent work of scholarship and one of which the Institute could well be proud.

With regard to the staff of the Institute, Mr. A. E. Chattin had retired at the end of the year from the position of Assistant Secretary, which he had held for

32 years. For the last five of these he had also been in charge of the Library and Information Department. He was continuing his connection on a part-time basis. On behalf of the Members and the Council, the President thanked Mr. Chattin for his loyal and devoted service to the Institute. (*Applause.*)

The **Honorary Treasurer** (Mr. W. Barr, O.B.E.), in presenting the Accounts and seconding the President's motion, said that the Institute was now spending money at the rate of £95,000 per annum, £10,000 more than the previous year. He was happy to report, however, that the income more than balanced the expenditure, the income of £97,964 leaving the Institute, after charging certain special items, with the sum of £1801 excess of income over expenditure. This had been transferred to the Accumulated Fund. Transfers amounting to £1750 had been made from the Accumulated Fund to Reserves, and the balance stood at £28,990, slightly more than in the previous year.

During the year a further £1616 had been written off the value of the lease of No. 4 Grosvenor Gardens. The total amount written off this lease, which ran for 60 years from September, 1955, was £7281, and its value in the Balance Sheet today stood at £36,697.

The motion for the adoption of the Report of Council and the Statement of Accounts was carried unanimously.

ELECTION OF MEMBERS

The scrutineers reported that the following candidates for membership had been duly elected:

Members

Asbury, Allan, B.SC.(HONS.), M.I.E.E. (Stoke-on-Trent); **Ashton-Martin,** Clinton Desmond, B.A.(HONS.), B.E.(HONS.) (Sydney, N.S.W., Australia); **Ayres,** J. R. (Thornaby-on-Tees); **Banks,** Francis Richard (West Bromwich); **Beer,** Stafford (Sheffield); **Bell,** Kenneth William (Sheffield); **Billings,** John, B.SC. (Vancouver, B.C., Canada); **Billington,** Jack Charles, PH.D., D.I.C., A.R.S.M. (Birmingham); **Bird,** Frederick Corin, A.I.M. (Halesowen); **Blake,** Paul Desmond, M.A. (Waltham Cross); **Bloom,** Ray A., M.S.(MET. ENG.) (Canton, Ohio, U.S.A.); **Boddington,** Anthony James (Birmingham); **Bond,** Terence Henry Lloyd, L.I.M. (Wednesbury); **Bone,** Davis Charles, A.C.A. (Newport, Monmouthshire); **Broomhead,** Arthur, A.MET. (Sheffield); **Brotherton,** Peter Albert John, L.I.M. (Darlaston); **Bucknell,** George Leonard, M.A. (CANTAB.) (London); **Cameron,** James Adam, B.SC., D.R.T.C. (West Bromwich); **Cardano,** Renato, A.I.M. (Terni, Italy); **Choan,** Ko Kim, B.SC. (Manila, Philippines); **Connor,** Henry, B.SC.(HONS. CHEMISTRY) (London); **Constant,** André (St. Germain-en-Laye, France); **Corlett,** Walter Harold (Shotton, Chester); **Corry,** Fred, ASSOC. M.C.T., F.I.M. (Sheffield); **Cosby,** William Trevor, B.SC., PH.D., A.M.INST.F., A.M.INST.GAS E. (Huddersfield); **Coyne,** Terence John (Sheffield); **Deutsch,** Jorge F. (Buenos Aires, Argentina); **Dodd,** Charles Aaron, A.M.I.E.E. (London); **Drake,** Peter Francis, A.MET., L.I.M. (London); **Drysdale,** Royston Fraser, A.I.M. (Dorking); **Edström,** John Olof (Sandviken, Sweden); **Ely,** Colin Frederick (Stockport); **Falvey,** Denis Joseph, B.SC.(ECON.)(HONS.) (London); **Feasey,** Raymond James, A.I.M. (Birmingham); **Fenner,** Gerald Oxton (London); **Fischel,** John Hans (Newcastle-upon-Tyne); **Forss,** S. Lennart (Riverton, N.J., U.S.A.); **Füssl,** Erwin, DIPL.ING. (Zürich, Switzerland); **Gaines,** John M., M.S., PH.D. (New York, N.Y., U.S.A.); **Garfield,** Francis, B.SC. (Widnes); **Gasper,** Robert Arthur (London); **Gillemot,** Laszlo, D.SC.TECH., DIPL.ING. (Budapest, Hungary); **Gopal,** N. A., B.E. (Jamshedpur, Bihar, India); **Gousseland,** Pierre (Paris, France); **Gregory,** James Alfred (Newcastle, N.S.W., Australia); **Groves,** Leslie George, M.SC., PH.D., A.M.I.CHEM.E. (Harlow); **Guest,** Bertie Warner (London); **Hayward,** Fred Malcolm (Manchester); **Heppenstall,** Robert B., B.A. (Pittsburgh, Pa., U.S.A.); **Hill,** Sidney James Thomas (London); **Holleman,** Dr. J. W. (Rotterdam, Holland); **Hooper,** John Joseph (London); **Hubbard,** Frederick Gordon Albert (Newcastle, N.S.W., Australia); **Johnson,** Henry Hulme, A.I.M. (Chester); **Johnson,** Herbert H., Jr., M.S., PH.D. (Bethlehem, Pa., U.S.A.); **Johnson,** Oscar G., B.CHE. (Los Angeles, Cal., U.S.A.); **Johnson,** William R., B.S.(MET.) (Bristol, Conn., U.S.A.); **Kellaway,** F. W., B.SC. (Letchworth); **Kent,** Robinson Pearson, L.I.M. (Newcastle-upon-Tyne); **Kynoch,** Kenneth Douglas (Vereeniging, Transvaal, South Africa); **Lakho,** Abdul Rasool M., B.SC. (Karachi, Pakistan); **Lamb,** Richard Barry, J.P. (Annan); **Laurie,** William Charles, M.INST.B.E., C.INST.W. (London); **Lawley,** Lindsay Cecil, F.R.ECON.S. (Stourbridge); **Lee,** Morgan Hamilton, L.I.M. (Swansea); **Leigh,** F. S., B.SC. (Birmingham); **Leyshon,** Humphrey James, B.SC.(HONS.) (Birmingham); **Longworth,** George Herbert, B.SC. (Manchester); **McCallum,** Neil, B.SC.(HONS.), PH.D., A.R.T.C., D.I.C. (Coatbridge); **McCutcheon,** Kenneth C., M.E. (Ashland, Ky., U.S.A.); **Marple,** Thomas George, M.INST.C.E., M.I.MECH.E. (Barrow-in-Furness); **Marriott,** James Bruce, B.SC., PH.D., A.R.T.C. (Glasgow); **May,** Douglas (Birmingham); **Miller,** Archibald, B.SC. (Workington); **Mills,** James Thomas (Ebbw Vale); **Miranda y Benito,** Antonio Fernandez (Aviles, Asturias, Spain); **Mitchell,** Joseph (Manchester); **Montgomery,** John, (Glasgow); **Moore,** Marcus, B.SC., A.M.I.STRUCT.E. (Sheffield); **Moreton,** Brian Berkeley, B.SC.(MET.)(HONS.) (Birmingham); **Nandi,** Rathindra Kumar, B.SC.(MET.), L.I.M. (Laban, Assam, India); **Nikander,** Carl-Johan, M.SC.(ENG) (Helsingfors, Finland); **Oliver,** Kenneth Arthur, L.I.M. (Newcastle-upon-Tyne); **Oswin,** Eric Herbert, A.MET., A.I.M. (Rotherham); **Oxley,** Harvey, A.MET., A.I.M. (Sheffield); **Patton,** Alexander Martin, B.A.(CANTAB.) (Birmingham); **Philip,** T. V., M.S.(MET.ENG.), PH.D., A.I.M. (Pittsburgh,Pa., U.S.A.); **Pietiläinen,** Lauri A., DIPL.ING. (Imatrankoski, Finland); **Plankensteiner,** Siegfried, DR.MONT., DIPL.ING. (Ternitz, Austria); **Purse,** James N., B.SC.(MET.ENG.) (Cleveland, Ohio, U.S.A.); **Ramachandran,** S., B.ENG. (Jamshedpur, Bihar, India); **Reicher,** Georges William (Brussels, Belgium); **Rieger,** J. C. (Cleveland, Ohio, U.S.A.); **Robertson,** James Anderson (London); **Robson,** Robert, M.A., PH.D. (London); **Russell,** John V., M.S.(MET. ENG.) (Chicago, Ill., U.S.A.); **Seguin,** Paul Henri (London); **Semkowicz,** Adam (Warszawa-Mlociny, Poland); **Senior,** Bernard Haydn (Sheffield); **Septier,** Louis (Saint Germain-en-Laye, France); **Smith,** Alan Daniel, A.M.I.MECH.E. (London); **Smith,** Eugene Monroe, M.S. (Coatesville, Pa., U.S.A.); **Smith,** John Young, B.SC. (Sheffield); **Smith,** Thomas James Jackson, B.SC., A.R.T.C., A.I.M. (Sheffield); **Spence,** Wilfred James (West Hartlepool); **Spence,** William, B.SC.(HONS.), A.M.I.MECH.E., M.I.E.E. (Rugby); **Thacker,** Douglas, B.SC.(HONS.) (Sheffield); **Thomas,** Angus Arnold, M.A., A.M.I.MECH.E. (Sheffield); **Thomas,** Hiram Trevor (Kidwelly); **Thomas,** Jeffrey Haig, B.SC.(ENG.) 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Associate Members

Arrowsmith, James Michael, B.A.(CANTAB.) (Cambridge); **Ashworth,** Peter F., B.SC. (Ebbw Vale); **Baker,** Alan James, B.A. (Cambridge); **Baldwin,** Peter Harris, B.MET. (Northfleet); **Bale,** Michael Godfrey (Cardiff); **Ball,** Gerald, L.I.M. (Birmingham); **Barker,** William (Swansea); **Beardmore,** Peter (Sheffield); **Beech,** John (Sheffield); **Benas,** G. R., B.MET. (Corby); **Campbell,** Michael Clement, B.SC.(CHEM.), B.E.(CHEM.ENG.) (London); **Clarke,** Donald (Stoke-on-Trent); **Coulson,** John Michael Dudley (Newcastle-upon-Tyne); **Cowlin,** John Barrington (Swansea); **Davies,** David Emrys (Swansea); **Derricott,** Robert Thomas (Oldbury); **Dietz,** Dennis George (Middlesbrough); **Evans,** Eden M. H. (Swansea); **Evans,** William David (Swansea); **Finney,** Ernest David (Newcastle-upon-Tyne); **Haggett,** R. G. (Cambridge); **Hall,** Roger (Cambridge); **Hardy,** Roy (Newcastle-upon-Tyne); **Headworth,** David Martin, B.SC. (Cardiff); **Hicks,** Brian (Swansea); **Hinchliffe,** Arthur Anthony (Newcastle-upon-Tyne); **Hingorani,** Pritamdas, DIPL.ING. (Geisweid, West Germany); **Hopkins,** David Terence (Swansea); **Hugill,** John Martin (Newcastle-upon-Tyne); **Humphreys,** David Edward, B.SC.(HONS.MET.) (Sheffield); **Jefferies,** Walter (Newcastle-upon-Tyne); **Kaufmann,** Aubrey (Newcastle-upon-Tyne); **Knight,** John, A.MET., L.I.M. (Sheffield); **Lakeland,** Kenneth Donald (Brisbane, Queensland, Australia); **Lingard,** John Harry (London); **Littauer,** Ernest Lucius (London); **Moon,** John Robert, B.SC.(HONS.MET.) (Cardiff); **Moseley,** John Michael (Birmingham); **Murray,** John Graham DeBois (Cambridge); **Ogg,** Anthony Frederick (Swansea); **Pursall,** Peter (Stoke-on-Trent); **Ray,** Malcolm John (Wolverhampton); **Reynolds,** Geoffrey Laurence (Swansea); **Richards,** Geoffrey Llewellyn (Cardiff); **Sheldon,** Derek William (Wellington, Shropshire; **Shore,** Terence Michael (Sheffield); **Smith,** David (Newcastle-upon-Tyne); **Sunter,** Brian James, L.I.M. (Aylesbury); **Thomas,** Alan John (Swansea); **Thomas,** John David (Llanelly); **Thomas,** William Hywel James (Cardiff); **Tipper,** Peter William (Newcastle-upon-Tyne); **Worthington,** Peter John, B.SC.(HONS.) (Sheffield); **Wright,** Keith (Consett); **Wright,** Maurice Arthur (Swansea).

The **President** declared the applicants duly elected; they numbered 123 Members and 55 Associate Members, and the total membership of the Institute was now 4995.

GREETINGS TO THE INSTITUTE

The **Secretary** (Mr. K. Headlam-Morley) read telegrams which had been received from Professor Calbiani, President of the Italian Metallurgical Association; Jernkontoret, Sweden (signed by Mr. E. Wijkander, the President, Mr. R. Sunden, the Managing Director, and Mr. U. Notini, the Director of Research); from Professor

Dr. R. Durrer, of Switzerland (*Honorary Vice-President*); from Dr. Howard Biers, of the U.S.A. (*Honorary Member*); from Monsieur Daum, of the High Authority of the E.C.S.C.; and from Mr. B. F. Fairless, on behalf of the American Iron and Steel Institute.

ANNOUNCEMENTS BY THE SECRETARY

Changes on the Council

Since the last General Meeting, in September, 1957, the following had become:

Vice Presidents: Mr. E. T. Judge, Mr. F. H. Saniter, Dr. C. Sykes, C.B.E., F.R.S., Mr. S. Thomson. In addition the Council, at their meeting that morning, had elected Mr. D. A. Oliver, C.B.E., a Vice-President.

Members of Council: Dr. J. H. Chesters, Mr. F. B. George, Mr. W. F. Gilbertson, Dr. L. B. Pfeil, O.B.E., F.R.S. In addition the Council, at their meeting that morning, had decided to invite Mr. R. F. Summers to join the Council.

Honorary Members of Council:

Marshal of the Royal Air Force THE LORD TEDDER, G.C.B., D.C.L., LL.D., President of The Institute of Metals, in place of Dr. L. B. Pfeil.

Mr. W. E. BARDGETT and Mr. E. J. BRADBURY, representatives of The Institution of Metallurgists, succeeding Mr. R. S. BROWN and Dr. L. B. PFEIL.

Mr. T. W. THURSFIELD, President of the Cleveland Institution of Engineers, in place of Mr. F. B. GEORGE.

Dr. C. BODSWORTH, President of the Liverpool Metallurgical Society, in place of Mr. J. S. W. GRAHAM.

Dr. K. M. ENTWISTLE, President of the Manchester Metallurgical Association, in place of Mr. G. A. COTTELL.

Mr. R. C. BAKER, President of the Sheffield Metallurgical Association, in place of Mr. P. JUBB.

Mr. E. D. BOOL, President of the Sheffield Society of Engineers and Metallurgists, in place of Mr. L. K. EVERITT.

Mr. J. CASWELL, President of the Swansea and District Metallurgical Society, in place of Mr. R. WALKER.

Retiring Members of Council:

In accordance with Bye-law 10, the names of the following Vice-Presidents and Members of Council were announced at the Autumn Meeting, 1957, as being due to retire at the present Annual Meeting:

Vice-Presidents: Mr. W. F. CARTWRIGHT, Sir CHARLES GOODEVE, O.B.E., F.R.S., Mr. N. H. ROLLASON.

Members of Council: Dr. J. W. JENKIN, Mr. F. H. SANITER (since elected Vice-President), Mr. T. JOLLY, Mr. R. A. HACKING, Mr. W. C. BELL.

No other members having been nominated up to one month previous to the present meeting, the retiring Vice-Presidents and Members of Council were declared to be re-elected.

Andrew Carnegie Scholarships

The following awards had been made since the last General Meeting:

£435 to R. E. M. BALL (Imperial College, London) to assist research on the effect of stored energy on the fracture characteristics of certain steels.

£50 to R. GILBERT (Liverpool University) to assist research on the M_s temperature in binary iron alloys with restricted gamma fields.

£400 (second grant) to T. GLADMAN (Sheffield University) to assist research on the effect of hydrogen on transformations in alloy steels.

£400 (second grant) to K. A. SALMON (Sheffield University) to assist research on the kinetics of the transfer of sulphur between iron and slag.

£50 (second grant) to J. S. WHITE (Liverpool University) to assist research on the effect of particle decomposition of austenite to lower bainite upon the completion of that decomposition to upper bainite.

Dates of Meetings

The following meetings had been arranged:

Special Meeting in Belgium and Luxembourg, 18th to 28th June, 1958.

Autumn General Meeting in London on 10th December, and NOT 26th November, 1958, as previously announced.

Annual General Meeting, 1959, in London on 6th and 7th May.

Special Meeting in Italy in September or October, 1960, by invitation of the Associazione Italiana di Metallurgia (Italian Metallurgical Association).

Meetings of the Engineers Group

Meetings of the Engineers Group would include: a meeting on 14th to 16th October, 1958, in Chester, with visits to works; a meeting on 11th December, 1958, in London, immediately after the Autumn Meeting, to discuss vacuum processes in the steel industry; and a meeting from 15th to 17th April, 1959, in Holland, by invitation of the President, to discuss ore treatment and handling in iron and steelworks and in ore-transfer stations and ports, with visits to his and other works.

ANNOUNCEMENTS BY THE PRESIDENT

Honorary Members of the Institute

In connection with the forthcoming Special Meeting to be held in Belgium and Luxembourg, he had great pleasure in announcing that His Majesty King Baudouin, King of the Belgians, and H.R.H. Charlotte, Grand Duchess of Luxembourg, had been graciously pleased to accept Honorary Membership of the Institute. This was not the first time that a King of the Belgians had become an Honorary Member of the Institute; King Baudouin's father, King Leopold III, his grandfather, King Albert, and his great-grandfather, King Leopold II, had also done the Institute the honour of becoming Honorary Members.

Additional Honorary Members of Council

The Council thought that it was in the interests of the Institute to arrange for wider representation of members on the Council. Accordingly, at their meeting on 12th March they had decided to co-opt not more than six additional Honorary Members of Council, who would normally serve for a period of three years. The Council had invited Mr. R. W. Evans and Dr. L. F. C. Northcott to join the Council this year, and they had agreed to serve. The Council hoped to invite two more members next year, and two more in the following year.

Organization of Meetings

The Council were not satisfied that in recent years the meetings of the Institute had been arranged in such a way as to meet the requirements of members in the changed conditions of the present-day world. There was today more specialization and people had less time for, and perhaps less interest in, subjects other than their own. A Committee had examined this problem, and the Council had adopted its recommendations.

As a result, a Meetings Sub-Committee would accept responsibility, under the Council, for the organization of meetings. A number of changes would be made,

including greater grouping of papers and the organization of meetings to discuss selected subjects of current interest. From time to time it was hoped to arrange lectures of more general appeal, and there would also be meetings in steelmaking districts. It was hoped that many would be held in conjunction with the Local Societies. Nothing revolutionary was intended, but it was hoped that the changes would mean an improvement.

Golden Jubilee of The Institute of Metals

The Institute of Metals was celebrating its Golden Jubilee this year, and the Golden Jubilee Spring Meeting of the Institute had been held a week ago. On behalf of all the members of The Iron and Steel Institute he expressed their congratulations to The Institute of Metals. In the short space of fifty years it had attained a position of acknowledged pre-eminence in its field throughout the world. He would like also to congratulate all concerned on the magnificent organization of the Golden Jubilee meeting and on behalf of The Iron and Steel Institute to send good wishes to the President of The Institute of Metals for its future success.

PRESENTATIONS

Bessemer Gold Medal

The **President** announced that the Bessemer Gold Medal for 1958 had been awarded to Mr. W. F. CARTWRIGHT (Steel Company of Wales, Ltd.), in recognition of his distinguished contributions in the field of the design, development, and organization of modern iron and steelworks and in the furtherance of steelworks engineering in all its branches.

Mr. Cartwright had an outstanding and well-deserved reputation in the steel industry. The plants which had been built and were running under his responsibility were proof of his excellent qualities as an engineer and a manager and were the result of sound judgment and experience and of a critical study, not only of national developments, but also of what had been happening in foreign countries. In the Institute Mr. Cartwright's publications and his work on the Council and Committees, especially for the Engineers Group, were outstanding and of very great importance.

In reply, **Mr. Cartwright** mentioned that he had been trained by a Bessemer Medallist, Mr. J. S. Hollings. He had understood the need for anyone in authority to train someone to take his place when he had to retire, and had taken immense trouble over training Mr. Cartwright for his present post.

Mr. Cartwright said that he was under no delusion that he was a genius, either as a metallurgist or as an engineer; he had merely been in the right place at the right moment. The great project in South Wales drew to it a large number of people of considerable ability in the technical world. He had had to pick out the plums from the huge cake which was offered.

Sir Robert Hadfield Medal

The **President** presented the Sir Robert Hadfield Medal for 1958 to Mr. W. C. F. HESSENBERG (British Iron and Steel Research Association), for his distinguished career in that Association and for his contribution to rolling mill research.

Andrew Carnegie Silver Medal

The **President** presented an Andrew Carnegie Silver Medal for 1957 to Mr. S. W. K. SHAW (then of Sheffield University; now with the National Gas Turbine Establishment) for his report on "The Formation of Carbides in Low-carbon Chromium–Vanadium Steels at 700° C" (*J.I.S.I.*, 1957, vol. 185, Jan., pp. 10–22). Mr. Shaw's co-author, Professor A. G. Quarrell, was not eligible for the award.

Williams Prize

The **President** presented a Williams Prize for 1957 of £100 jointly to Mr. C. HOLDEN and Mr. A. D. ROBERTSON (United Steel Companies Ltd.) for their paper on "Protection of Refractories by Moving Air Curtains" (*J.I.S.I.*, 1957, vol. 185, Feb., pp. 177–200). Their co-author, Dr. J. H. Chesters, was not eligible.

Ablett Prize

The **President** announced the award of an Ablett Prize of £100 jointly to Mr. C. E. H. MORRIS and Mr. R. N. DALE (Steel Company of Wales Ltd.) for their paper on "Planning the Conversion of a High-Lift Slabbing Mill to a Universal Mill" (*J.I.S.I.*, 1957, vol. 185, Apr., pp. 532–552). At the suggestion of the Engineering Committee, the award would be made at a meeting of the Engineers Group.

INDUCTION OF NEW PRESIDENT

Before inducting the President-Elect into the Chair, the **President** spoke of the great honour which had been accorded to him by electing him as President of the Institute, and of his own pleasure during the past year. He expressed his sincere thanks to the Council, and especially to the inner circle of Past-Presidents, whose support had always been forthcoming, and also to the Secretary and staff of the Institute.

His successor, Mr. C. R. Wheeler, C.B.E., had had a brilliant career in the steel industry, which should be an indication of the wisdom of the Council's choice in electing him as President. He was also one of the youngest Presidents the Institute had ever had.

VOTE OF THANKS TO THE RETIRING PRESIDENT

The new **President** (Mr. C. R. Wheeler, C.B.E.), proposed a vote of thanks to Mr. Ingen-Housz, who had been, he said, an outstanding President, with an outstanding supporter in Mrs. Ingen-Housz. He had been the first foreign President for forty years, and had set a standard for a great many years to come, by virtue of his industry, his geniality, and his competence.

The vote of thanks was seconded by the **Hon. R. G. Lyttelton** (*Past-President*) and carried with acclamation.

PRESIDENTIAL ADDRESS

The **President** then delivered his Presidential Address, entitled "Raw Material Supplies and the Future Development of the Iron and Steel Industry" (*J.I.S.I.*, 1958, vol. 189, June, pp. 101–109).

A vote of thanks to the President for his address, proposed by **Mr. R. Mather** (*Past-President*) and seconded by **Sir Robert Shone,** C.B.E., was carried with acclamation.

TECHNICAL SESSIONS

A number of papers was presented and discussed at technical sessions on the following day. Details are given in the News section of the April issue of the *Journal* (p. 389). Reports of the discussions will be published later in the year.

DINNER FOR MEMBERS

The annual Dinner for Members was held at Grosvenor House, Park Lane, London, W.1, on the evening of Wednesday, 7th May, and was attended by about 1500 Members and guests. The toast of "The Iron and Steel Institute and Industry" was proposed by the Rt. Hon. Reginald MAUDLING, P.C., M.P., Her Majesty's Paymaster-General; the President replied. The health of the guests, proposed by Sir Andrew MCCANCE, D.SC., LL.D., F.R.S. (Past-President and President of the British Iron and Steel Federation), was replied to by Mr. P. VAN DER REST, President of the Groupement des Haut Fourneaux et Aciéries Belges.

Early Industrial Production of Bessemer Steel at Edsken

By Per Carlberg

BY THE MIDDLE of the nineteenth century, the time was opportune for the development of methods for making steel in large quantities in order to meet the demands of the rapidly expanding railway and engineering industries. As is well known, Henry (later Sir Henry) Bessemer was the pioneer in this field. He had observed, as many others had done, that the carbon content of molten pig iron, in a refining furnace for example, could be slowly reduced by the action of streams of air impinging on its surface. It required his genius to deduce that this action would be more efficient if air were forced through the molten metal, and that the temperature would rise sufficiently without the use of additional fuel. The principle of "iron and steelmaking without fuel" was established.

Fundamental British patent applications concerned with steelmaking were registered by Bessemer at the Patent Office on 15th March, 1856 (No. 630) and 31st May, 1856 (No. 1292), where they were open to examination by anyone, but they were not printed at that time; earlier patents relating to this invention are, however, in existence. The corresponding Swedish patent (No. 35) was granted on 1st July, 1856, and printed in the Swedish official journal on 29th July. The invention became widely known after Bessemer's famous lecture to the British Association on 11th August; this was fully reported in *The Times* of 14th August, 1856,* and *The Illustrated London News* of 30th August gave a good description of the method, with ample illustrations.

It is one thing to make an invention, but it is quite different to make it into a practical proposition. The centenary of the invention was most properly celebrated by The Iron and Steel Institute in 1956, but the centenary of its practical realization, however, falls in July, 1958.

The Swedish patent (No. 35) was sold by Bessemer and Longsdon to Hoare, Buxton and Co. of London, for £10,000; the indenture is dated 27th April, 1857. Preliminary experiments were carried out at Dormsjö, Sweden, a partner of the company which brought the patent having an interest in these works.

Hoare, Buxton and Co., a firm of merchants and bankers in London, were in fact the agents of Daniel Elfstrand and Co. of Gefle, Sweden, a well-known firm of shipwrights, shipowners, and exporters dealing in timber and wrought iron. This Swedish company had recently acquired the Forge of Högbo, with its small blast-furnace at Edsken, about 40 miles west of Gefle, a Baltic seaport situated some 100 miles north of Stockholm. The head of the company, G. F. Göransson, went to London in May, 1857, where he bought on behalf of his firm one-fifth of the rights to Swedish patent No. 35, which gave it the right to a part of any licence fees or royalties, as well as the right to manufacture up to 500 tons (*sic*) of steel a year on payment of 2*s*. per ton in royalty. The price was £2000, of which the first half was paid on 1st June. The transaction was confirmed in a letter from Richard Stuart Lane, a partner of Hoare, Buxton and Co., but many difficulties had to be surmounted before it was completed from a legal standpoint in 1859, in the form of an imposing document on vellum measuring 29 in. × 23 in.

The equipment was ordered from Messrs. W. and J. Galloway of Manchester; the order comprised two fur-

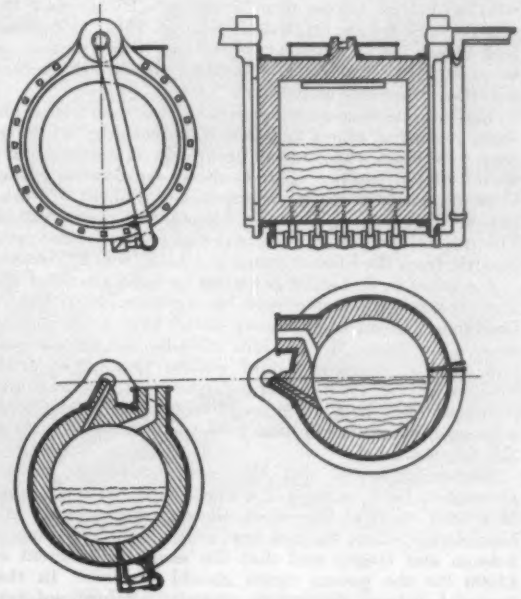


Fig. 1—The Bessemer converter as used at Edsken from 3rd November, 1857, to March, 1858, after a contemporary sketch

Manuscript received 20th May, 1958.

Mr. Carlberg is with Sandvikens Jernverks AB, Sweden.

* Reproduced in *J.I.S.I.*, 1956, vol. 183, June, between pp. 180 and 181.

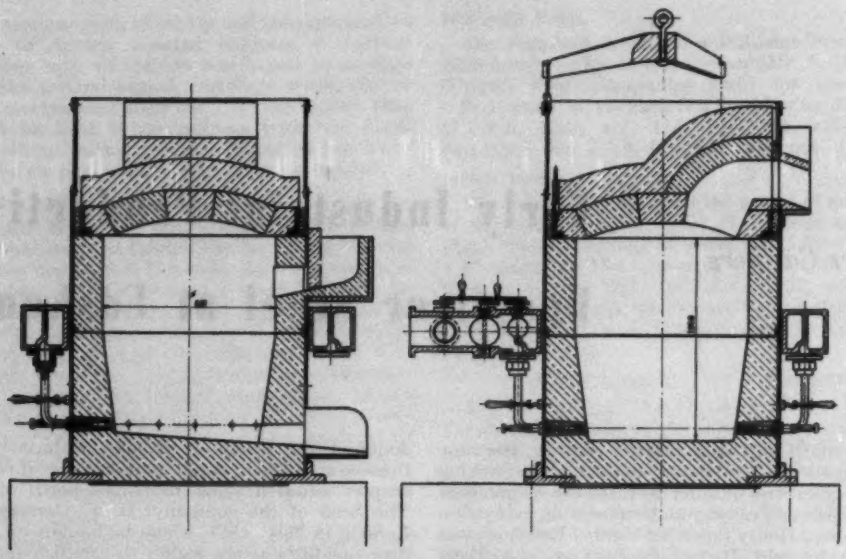


Fig. 2—The upright converter as used at Edsken about 18th July, 1858 (modern reconstructed drawing)

naces, a large boiler, and a steam blowing engine with one cylinder delivering air to the blast-furnace and the other to the converters by means of the same piston rod as the steam cylinder. Later calculations show a rating of about 70 h.p. for the engine. Delivered in early August, 1857, the equipment was shipped to Gefle and transferred by rail to the railhead of the Gefle–Dala Railway, then under construction. The final stage of transport to Edsken, over 13 miles of primitive roads, was a heavy task, requiring some 60 men and numerous horses. The erection was supervised by a Mr. Price of Manchester, who left Edsken before 10th November. By the time the experiments began, on 3rd November, 1857, Göransson had spent the equivalent of a year's production of wrought iron at the Högbo Forge to purchase the patent and the equipment at Edsken.

The Bessemer furnaces were cylindrical, with horizontal axes, measuring about 2½ ft inside diameter by 4 ft long; they were lined with English firebricks. A contemporary sketch of the furnace (Fig. 1) shows an unusual tilting Bessemer converter, very cramped and difficult to work; one end had to be opened for cleaning and maintenance. The normal weight of one charge of pig iron, conveyed directly from the blast-furnace in a ladle, was 23 cwt.

A certain C. J. Leffler is known to have attended the first experiments as an expert, having been instructed by Bessemer. In an early report dated 12th December, a master mechanic, Mr. Lindahl of Gefle, tells Göransson how he had hammered and welded two ingots from Edsken at the Robertsholm Forge (now Hofors), and from the steel had made some tools which, he wrote, were as good as if they had been made from the "best English cast steel."

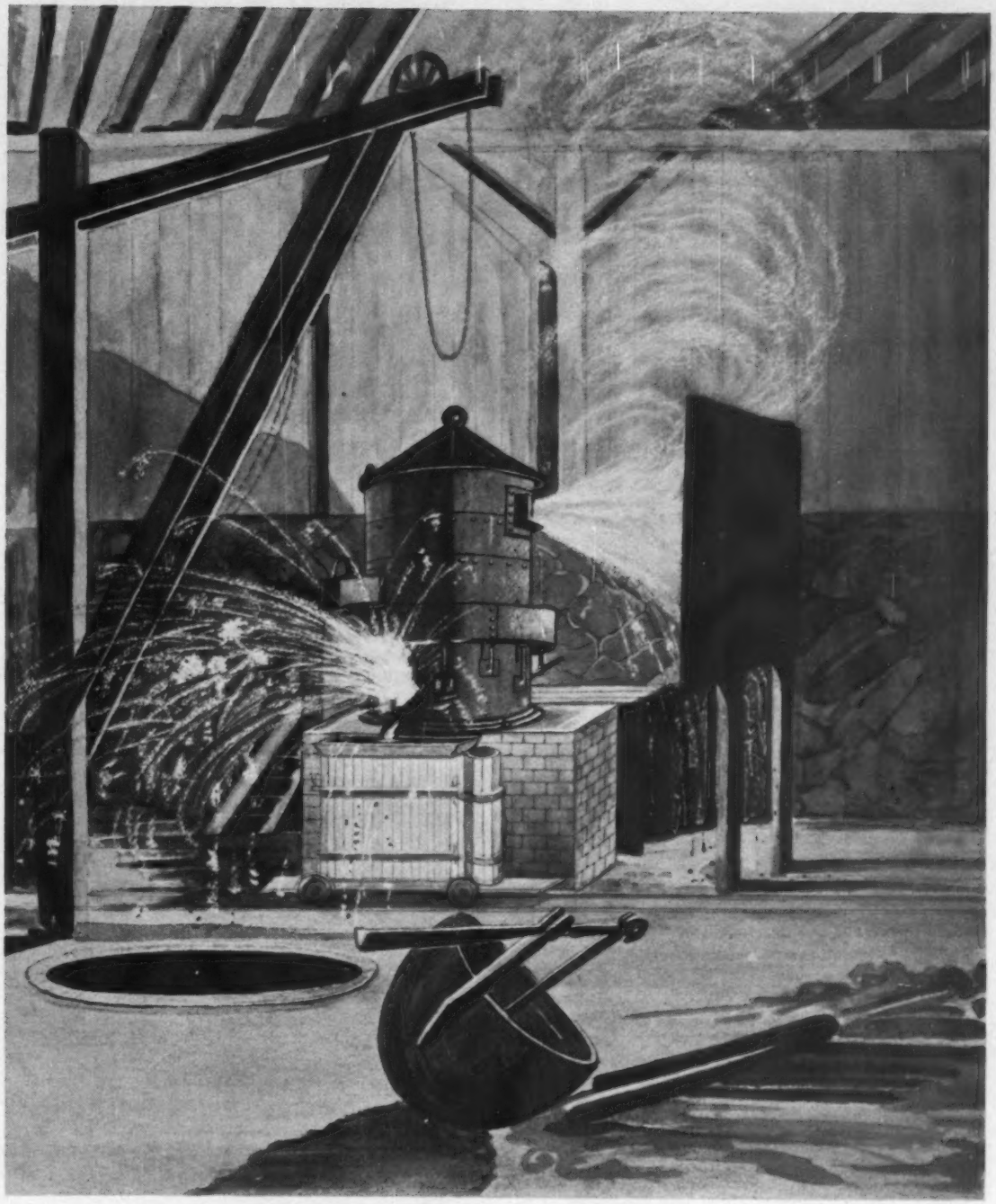
Daniel Elfstrand and Co. went bankrupt on 1st December, 1857, victims of a world-wide chain reaction. However, on 22nd December, the administrators of the bankruptcy estate decided that work should continue at Edsken and Högbo and that the second instalment of £1000 for the patent rights should be paid. In this financial distress, Göransson appealed to Jernkontoret; he sent to a prominent member of its Board some of the samples made by Lindahl and also samples of 18 in. × 24 in. Bessemer steel plates rolled at a nearby works.

Jernkontoret reacted with speed. On 5th January, 1858, C. O. Troilius, an Inspector of Mines and a member of the Board of Jernkontoret, and P. D. Malmquist, a member of its technical staff, officially visited Edsken, where they followed the melting of three charges. From Edsken they went to Högbo on 7th January to watch the ingots being hammered and welded. The result of their very comprehensive report, dated 10th January, was that on 15th January the Board of Jernkontoret granted the administrators a loan to cover the costs of a steam hammer and some tilting hammers at Högbo. Andreas Grill, an experienced metallurgist of the staff of Jernkontoret, was appointed to follow the experiments, assisted by junior members of the Jernkontoret staff; one of them was always on duty at the Edsken works.

In their report, Troilius and Malmquist made some significant comments: (1) certain local ores, liable to give red-short iron, had already been omitted from the burden; (2) it was important that the blast-furnace should work smoothly, giving a grey, or mottled grey and white, pig iron; (3) one of the charges had given the best fluidity, probably because the tuyeres were worn and so wider, thereby admitting more air.

The experiments were resumed early in March after one month's interruption to repair the blast-furnace. A fixed standing converter, similar to the one at Baxter House, had by then been delivered by the Forsbacka steelworks, followed later by a second one. They were lined with Swedish firebrick or rammed with Höganäs fireclay and quartz.

The experiments were designed to speed up the process and diminish the heat losses. Originally, the tuyeres were fitted at two levels, which, of course, did not prove satisfactory. At last, by mid-July, the furnace had taken on the familiar form and size (Fig. 2). The casting technique had also undergone drastic development: direct casting from the tilting or fixed furnace, which caused considerable loss of steel, was replaced by a technique that used a ladle, fitted with a bottom hole and a stopper, to take the steel to the moulds. Provided that it was at a suitable temperature, the steel could be left in the ladle long enough for some of the slag to float to the surface before it was poured into the moulds; this important



"Bessemer Blow 1858 at Edske Blast-furnace, Sweden"

After a water-colour by Carl Cantzler

[*Carlberg*
[*To face p.* 202

Bessemer Blow 1858 at Edske Blast-furnace, Sweden

The picture shown overleaf is a copy of the water-colour by Carl Cantzler painted in 1858, which is in the archives of the Sandvik Steel Works Ltd., Sandviken, Sweden. It was presented to The Iron and Steel Institute in 1956 on the occasion of the centenary of the first announcement of the Bessemer process by Mr. K. F. Göransson, Chairman of the Sandvik Steel Works Ltd. It now hangs in the Offices of the Institute at 4 Grosvenor Gardens, London, S.W.1.

Carlberg]
To face p. 203]

improvement was introduced in May. In July, successful experiments were also made with rising ingots; the usual sizes of these ingots were 8 in., 6 in., or, exceptionally, 4½ in.

The pig iron was, of course, made with charcoal. No reliable contemporary analyses of ores have been found, but some analyses, selected from a publication by Jernkontoret and given below, will give a general idea of the types of ore used. It should be noted that the ores have only small manganese contents.

The burden consisted in January, 1858, of:

Stora Bispberg No. 1	34·1%	denoted *A*
,, ,, No. 2	6·9%	,, *B*
W. Bispberg and Prestgrufva	13·7%	,, *C*
Norberg (red hematite)	6·9%	,, *D*
Rällingberg No. 2	20·4%	,, *E*
Limestone	18·0%	
	100·0%	

Analyses

Year of Analysis	Fe_2O_3	Fe_3O_4	FeO	MnO	MgO	CaO
(*A*) 1883	7·8	84·2	—	0·10	1·07	0·58
(*B*) 1874	7·2	74·6	—	tr.	0·54	0·80
(*C*) 1874	75·0	—	—	tr.	0·18	0·40
(*D*) 1874	49·4	16·6	—	0·05	1·11	2·57
(*E*) 1883	—	87·8	—	0·52	3·05	2·33

Year of Analysis	Al_2O_3	SiO_2	Fe	P	S
(*A*) 1883	0·21	6·91	66·4	0·004	0·005
(*B*) 1874	0·52	3·42	69·3	0·002	—
(*C*) 1884	2·01	24·5	52·5	0·020	0·010
(*D*) 1884	0·84	28·6	46·6	0·023	0·015
(*E*) 1883	0·26	8·3	58·2	0·007	0·001

The Jernkontoret loan was given on the condition that the Jernkontoret partners should have the right to test a limited quantity of their own ores at Edsken. The most noteworthy test was that of Dannemora ore in March, 1858, which gave a very good result; other more or less manganese-bearing ores also gave fairly good results. Grill observed at a later date that ores with some manganese were good for making soft steel. Of course, there were no facilities for chemical analysis at Edsken; one had

Fig. 3—Photomicrograph of table-knife, made from steel produced at Edsken before 1863. Note the very small slag inclusions × 300

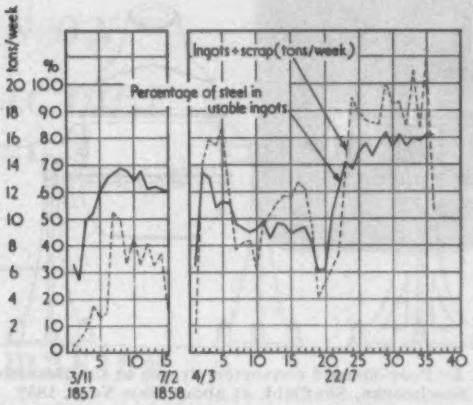


Fig. 4—Diagram of weekly steel production at Edsken from 3rd November, 1857, to 31st October, 1858.

to look at the texture of broken ingots and try the steel under the hammer. The steel was poured when the sparks and flames from the converter seemed to indicate to the experienced foreman that the steel had the desired hardness.

One small ingot from Edsken, probably made in 1858, was recently described* by Mr. K. F. Göransson. Nothing is, however, said about non-metallic impurities in the steel. A recent examination of a table-knife of steel from Edsken, probably earlier than 1863, shows an extremely clean steel, which seems to contradict the general opinion about the slag in early Bessemer steel. A photomicrograph of this specimen is shown in Fig. 3; its composition was:

C, %	S, %	Mn, %	P, %	S, %	Cr, %	Ni, %	Mo, %	Cu, %
0·76	tr.	0·04	0·030	0·005	0·01	—	—	0·02

The photomicrograph and the analysis were provided by the laboratory of Sandviken Jernverks AB.

The vicissitudes of the experiments are illustrated by Fig. 4, compiled from the account books of Edsken. Obviously, something occurred in the 20th week of the second campaign (i.e. immediately after 15th July); the percentage of steel in the ingots rose to a reasonable level and remained there for months. The diagram seems thus to illustrate the tradition according to which regular industrial production of Bessemer steel ingots began at Edsken on 18th July, 1858. This tradition also finds some confirmation in reports by Grill, published in *Jernkontorets Annaler* for 1859.

The part played by Bessemer in the Edsken experiments is not quite clear. Leffler was to have acted as an expert and a contact man, but by the spring of 1858 Göransson had lost confidence in him as an expert, and his visits at Edsken became shorter and less frequent. What Leffler wrote to Bessemer is unknown, but a letter, written in London at 4 Queen Street Place, Cannon Street, on 21st June, 1858, and addressed by Bessemer to Leffler for communication to Göransson is in the Sandviken archives. As it throws some light on the Swedish claims to some priority in the practical realization of the Bessemer process, some quotations from it are given below:

> ". . . you and myself would be greatly benefited by more frequently communicating . . ."
>
> ". . . it is still more important to communicate the defects of difficulties because the other party may have got over them . . .

* K. F. Göransson, *Metal Progress*, 1956, vol. 69, pp. 85–87.

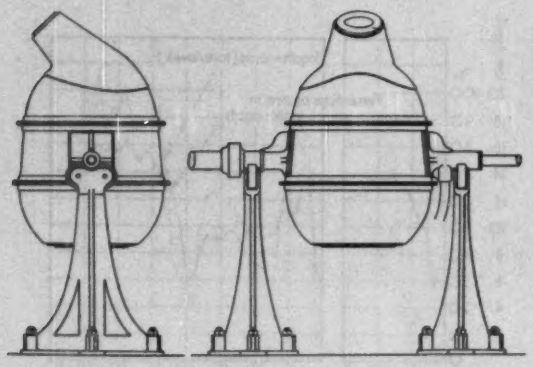


Fig. 5—Pear-shaped converter, drawn at the Bessemer Steelworks, Sheffield, at about New Year, 1859

. . . we shall in a few weeks commence work at Sheffield . . .

I will send you an account of any matters that can in any way be of service to you. I had intended to write to Mr. Urenson (*sic*) . . . " and further " . . . I should not like to be constantly writing on this subject without his knowledge and approval . . . "

He gives details about keeping the metal " in a mass " in order to reduce radiation losses and urges the construction of an upper chamber in the furnace and the discarding of the upper row of tuyeres, which had already been done. Certain advice about the number and size of tuyeres seems to indicate a development in the right direction, but the letter arrived too late to have any influence on the turning point of the Edsken experiments. He also discusses at length the possibility of controlling the type of steel by counting the number of strokes of the blowing engine, i.e. the volume of air supplied. Finally, he states that he was working with charges of 4·5 cwt of steel adding up to 1 cwt of scrap, and continues " I am so well pleased with the great energy and perseverance Mr. Urenson has displayed that I shall only feel pleased if I can lend a helping hand to the good work you have so far succeeded in . . . but ask in return all the information you can give . . . Have you tried manganese in any way . . . ?" He also asks for details about the pouring technique, comments on various methods of running pig iron into the converter, and refers to a converter at his own works in Sheffield which could be moved (tilted). It is not clear whether this is the horizontal cylindrical converter mentioned above, or an early example of the traditional pear-shaped one.

The experiments at Edsken were not kept secret. A Foreign Office report, dated 8/7/1858 at Stockholm and signed W. Spey, reads " . . . this experiment is considered to have practically succeeded . . . " Moreover, the works were open to visitors. From old accounts it has been possible to reconstruct a visitor's book for 1858; the visitors included many Swedish ironmasters and metallurgists, several people from France, Finland, Russia, and Austria, and at least two Englishmen: a guest of Mr. Petre's of Hofors and the foreman tilter at Högbo, Mr. Scholey. At Högbo, a 1-ton Swedish-made steam hammer had been put in operation on 15th May. One of the two forges was equipped with heating furnaces, and some tilting hammers. Edward Scholey, a forgeman and tilter from Wardsend, Ecclesfield, Yorkshire, had been in charge of the tilting and welding since March.

The ingots had to be hammered down very carefully. A 6-in. ingot was first hammered under the steam hammer and reheated eight times to bring it down to about 3 in.; it was then further reduced under the water-wheel hammers to about 1 in. thickness. Ingots were next welded with welding sand or clay and finally forged under the tilting hammers. The welding required great skill and the forgemen had to refund the value of any steel destroyed by careless heating or welding.

Fig. 6—The ruins at Edsken, 1957. The columns carried the charging flow of the blast-furnace. The opening below the figure housed the only tuyere of the blast-furnace. Foundations in the foreground are later than 1858

It was, in fact, a new product that was made at Edsken, steel in the form of ingots but not necessarily tool steel. As a first step towards introducing it on the world market, Göransson had a batch of ingots shipped to Sheffield and followed them there. They were hammered and welded in the presence of Bessemer and Göransson. Razors were made from some of the steel by I. Wostenholm and Sons of Sheffield (invoice dated 2nd Oct.), but these were later lost while being shipped to Sweden.

The good results obtained by Göransson at Edsken must have made a strong impression upon Bessemer, and on 8th October, 1858, his Sheffield company bought 100 tons of pig iron from Edsken. It was sold for £8 15*s.* 0*d.* per ton ex ship at Hull, and shipped at the end of October. It seems likely that this gave him some experience about the qualities required in pig iron for the Bessemer process.

At Edsken, the production of steel ingots went on during the following months and years, only interrupted by necessary repairs and sometimes by financial difficulties. New simple methods for analysing phosphorus and carbon, developed by Eggerz of Falun in 1859 and 1860, made possible a better control of the process and its product.

One development of some interest to the history of the Bessemer process should be noted. Bessemer sent a drawing of the later pear-shaped converter to Göransson (Fig. 5); this was accompanied by a letter dated 19th January, 1859, most likely written by Mr. Bessemer himself.

Production of Bessemer steel at Edsken went on till 1866 by which time the Sandvik steelworks had started and gradually taken over. The ruins of the Edsken plant at the present time are shown in Fig. 6.

Göransson and his staff at Edsken worked with enthusiasm and energy under sometimes very adverse conditions. Their perseverance prevailed and they put Bessemer's ingenious invention on a sound industrial footing, thereby inaugurating the age of steel.

PAPERS AND REPORTS ON RESEARCH AND PRACTICE

Metallurgy · Plant Operation · Research

Basic Open-hearth Steelmaking in the U.S.A.

By M. W. Lightner and D. L. McBride

SYNOPSIS

The basic open-hearth process continues to be the fastest growing steelmaking process in the U.S.A. Among the reasons contributing to the improvement in productive capacity of the open-hearth process are: extended-hearth furnaces with single uptakes, increased firing rates and greater use of oxygen for combustion, growing use of oxygen injection for decarburization starting immediately after the hot-metal addition, use of continuous waste-gas analysis to control the fuel and air input to the furnace, desulphurization of coke-oven gas and hot metal, improved control of bath temperature, and improved refractories and greater use of the all-basic furnace.

Important technological developments indicate that in the future open-hearth furnaces will be larger, heat times will be shorter, and fuel consumption will continue to be reduced; all of these can be achieved without sacrificing steel quality. 1542

A LITTLE OVER 70 years ago, the first basic open-hearth furnace in the U.S.A. was built in Cleveland, Ohio, in a plant which was formerly the Otis Steel Company. From this first furnace, with a capacity of 15 tons, the basic open-hearth process in America has grown until now there are 888 furnaces ranging in size up to 600 net tons, and the annual productive capacity is in excess of 120 million net tons of ingots and castings. This amazing growth has been accompanied by a similar broadening of the understanding of the technology of iron and steel and a distinct improvement in the quality of a vast array of steel products.

Because of recent technical developments, numerous statements have appeared in technical and trade journals predicting that the open-hearth process has passed its zenith, and, like the acid Bessemer process, will decline to a position of minor importance as a steelmaking method, being displaced by electric-arc furnaces and the newly developed basic oxygen converters. Certainly, a part of future steelmaking capacity increases will be through the electric furnace and the oxygen converter, but it should be recognized that economic aspects combined with availability of raw materials will govern the extent to which the open-hearth may be displaced. Despite claims to the contrary, the open-hearth process is still the fastest growing steelmaking process in the U.S.A. In fact, as shown in Fig. 1, all the growth in steelmaking capacity in the U.S.A. since 1935 has been confined to electric-arc furnaces and basic open-hearth furnaces charging hot metal.[1] The capacity of the acid Bessemer process has steadily declined, while that of cold-charged acid and basic open-hearth furnaces has remained virtually unchanged. There is a distinct similarity in the growth patterns of electric-arc furnace capacity and hot-metal basic open-hearth

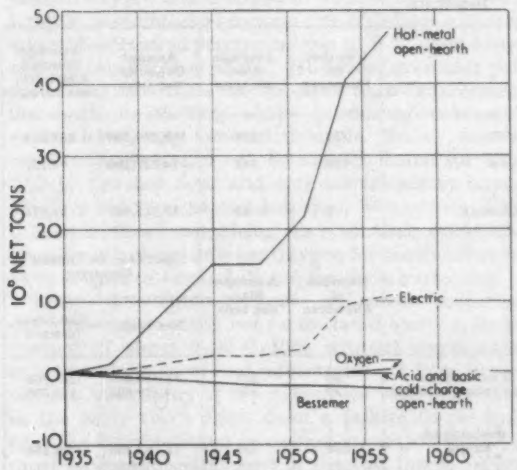


Fig. 1—Change in steelmaking capacity

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Dr. Lightner is Vice President, Applied Research, and Dr. McBride is Director of Metallurgical Process Development, Applied Research, of the United States Steel Corporation.

Table I

NUMBER OF OPERATING FURNACES

Source: "Directory of Iron and Steel Plants of the United States and Canada", American Iron and Steel Institute

	Acid Open-hearth	Basic Open-hearth		Electric Furnaces
		Cold Charge	Hot-metal Charge	
1935	58	194	756	Not available
1938	51	188	756	152
1945	50	170	770	262
1948	46	155	754	222
1951	37	149	761	256
1954	33	139	761	260
1957	35	129	757	268

capacity, but the growth in the latter has been nearly five times that of the electric-arc furnace. The top-blown basic oxygen steelmaking method was introduced in 1955 and is expected to reach a capacity of about 2 million net tons by the end of 1958.

A study of the records of the U.S. steel industry[1] reveals the way in which the increase of roughly 55 million tons in steelmaking capacity from 1935 to 1958 was achieved. One is first impressed by the fact that there has been virtually no change in the number of hot-metal open-hearth furnaces since 1935, and in the number of electric-arc furnaces since 1945. As shown in Table I, 756 hot-metal open-hearth furnaces were operating in 1935, and 757 in 1957. Similarly, the number of electric-arc furnaces changed only from 262 in 1945 to 268 in 1957. Also shown are the number of acid open-hearth furnaces and cold-charged basic open-hearth furnaces, for both of which there has been a substantial decrease in the number of operating units.

Since there has been essentially no change in the last 23 years in the number of hot-metal basic open-hearth furnaces, how then has it been possible to increase the annual capacity of these furnaces by nearly 50 million net tons of ingots and castings? As shown in Table II, this increase in steelmaking capacity has been due in part to the abandonment of obsolete open-hearth shops with small furnaces and the erection of several modern shops with very large furnaces. Also, the heat size of existing furnaces has been increased by widening and lengthening hearths, and by the use of light-weight ladles with welded construction and modern light-weight crane trolleys fabricated from high-strength constructional steels. In some cases it has been necessary to strengthen and to make major improvements to crane runways. More important, however, have been the improvements in material-handling methods and the greater realization of the importance of good combustion practices with respect to both furnace productivity and erosion of refractories. All this has led to longer furnace life, decreased fuel consumption, and shorter time of heat, so that the 12 h from tap to tap common 10 years ago is no longer considered acceptable and many shops are consistently maintaining a pace faster than 10 h from tap to tap. In fact, today there are at least 39 furnaces in the U.S.A. producing over 30 tons/h per 1000 ft² of hearth area, whereas 10 years ago few furnaces produced 20 tons/h per 1000 ft² of hearth area.

During the past 10 years the annual capacity of basic open-hearth furnaces charging hot metal increased by about 33·5 million net tons. Significantly, only one-third of this increase in capacity resulted from the construction of eight new open-hearth shops; the balance, or two-thirds of the increase in capacity, was accomplished by enlarging furnaces, by installing additional furnaces in existing shops, and by an improvement in practice resulting in shorter time of heat.

Unfortunately, it was not until about five years ago that the American Iron and Steel Institute began to collect much of the salient data on the operation of U.S. open-hearth furnaces. Although 10–15% of the open-hearth shops are not yet reporting all data, the accumulation of information will become extremely useful for measuring progress from year to year. Table III shows the trends for heat size, heat time, and unit roof life for about 85–90% of the stationary basic open-hearth shops charging hot metal, and the fuel consumption for all open-hearth furnaces.[2]

EXTENDED HEARTHS

About 1950, many years after the switch had been made from the use of producer gas as a fuel to the use of liquid fuels supplemented by coke-oven gas or natural gas, it became apparent that the new fuels permitted—one might even say, required—substantial changes in the design of the port ends. The double uptakes, with their large area, were found to be more of a detriment than an asset to furnace combustion. It was found that decreasing the uptake area not only improved combustion control but also allowed the hearth to be lengthened, thereby permitting shallower baths or preferably larger heat sizes without increasing bath depth. In the early cases, double uptakes were

Table II

HOT-METAL BASIC OPEN-HEARTH FURNACES IN THE U.S.A.: COMPARISON OF 1948 AND 1957

Source: "Directory of Iron and Steel Plants of United States and Canada", American Iron and Steel Institute

	Number of Furnaces	Average Size, net tons	Annual Capacity, net tons	Average Annual Capacity, tons/furnace
1957	757	196	148,289,100	143,011
1948	754	141	74,727,200	99,137
Change	+ 3	+ 55	+ 33,531,900	+ 43,874

	Number of Furnaces	Average Size, net tons	Increase in Annual Capacity	
			Net tons	Net tons/ furnace
8 new shops	50	287	11,360,000	227,200
14 enlarged shops	29	235	4,419,000	142,550
unchanged shops	678	187	17,752,900	26,184
Total	757	196	33,531,900	44,295

retained, whereas more recently the conventional double uptakes were replaced by a single uptake.

In the rebuilding process, uptake areas have been decreased by 16% to as much as 42%, permitting hearth areas to be increased by 25–35%. The increase in hearth area has generally been accompanied by a proportionate increase in heat size, although in several exceptional cases the heat size has been increased by as much as 100% with the tapping of double heats through bifurcated spouts into two ladles.

In the original design of liquid-fuel-fired furnaces, the hearth area occupied only about half the total floor area required for the furnace. With restricted uptakes and extended hearth areas, the hearth may occupy as much as 65% of the total area described by the outside dimensions of the furnace brickwork. Whereas the earlier designs generally provided an uptake area based on a firing rate of 850,000 B.t.u./h per ft² of uptake area (2·3 million kcal/h per m²), it has been found that the restricted single-uptake furnaces can be fired at 1,500,000 B.t.u./h per ft² of uptake area (4·0 million kcal/h per m²). The ultimate in restricted uptake furnaces is represented by the Maerz design, provided that such furnaces are equipped with adequate forced-air and waste-gas fans. At the moment there are three Maerz furnaces operating on an all-cold charge; the most recent furnace is being charged with about 60% hot metal. Performance records of these four furnaces will be watched with great interest.

USE OF OXYGEN

It is almost inconceivable that it should require over 100 years to develop a process for the manufacture of low-cost tonnage oxygen, a necessity for bringing to fruition its use as foreseen by Sir Henry Bessemer. However, as long ago as 1923 the potential improvement in production rates of steelmaking furnaces resulting from the use of oxygen for combustion[3] and decarburization[4] had been demonstrated by trials in commercial steelmaking furnaces at a time when oxygen was available only in bottles and at a cost of $240 per net ton. About 12 years ago the price of oxygen had dropped to $80 per net ton, and as a result, metallurgical oxygen (99·5%) began to come into widespread experimental use in U.S. open-hearth and electric-furnace shops. However, even this price prevented its routine use for other than decarburizing the bath in melting shops producing substantial quantities of very low-carbon steels. Today, tonnage metallurgical oxygen can be manufactured for about $12–15 per net ton, and commercial-purity oxygen (95%) is reported to cost less than $5 per ton. Thus, it is not at all surprising to find that many U.S. open-hearth shops now use oxygen for combustion and have sought to expand its use for decarburization.

Early development work indicated that bath decarburization could not be initiated above a carbon content of about 0·30–0·40% without encountering excessive damage to roof refractories. It later became obvious that many of the difficulties with refractories in the early trials arose from a failure to recognize that the large volumes of carbon monoxide generated must be considered as part of the fuel input. Within the past few years there has been a significant breakthrough in the search for a practice that would permit the use of oxygen for decarburization at any level of bath carbon content. In many U.S. open-hearths, oxygen injection for decarburization is started immediately after the hot-metal addition, and is continued until a few moments before the final tapping carbon content is reached. When more experience is gained with this new tool, the position of the open-hearth as the most versatile of all steelmaking processes will be further enhanced.

Table III

AVERAGE OPERATING DATA, U.S. BASIC OPEN-HEARTH FURNACES CHARGED WITH HOT METAL

Source: Reports of Refractories Committee and Technical Committee on Open Hearth Steelmaking, American Iron and Steel Institute

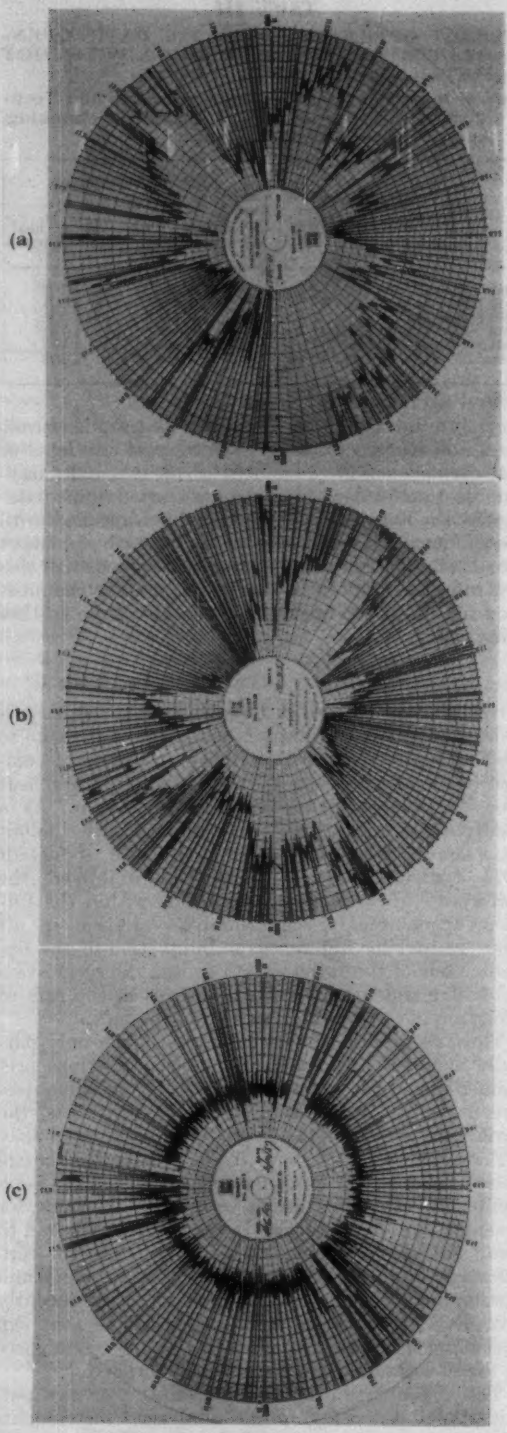
	Heat Size Net tons	Tap-to-Tap Time	Tons per hour	Unit Roof Life	Fuel Consumption	
					Million B.t.u. per net ton	Million kcal per metric ton
1951	—	12 h 06 min	—	—	4·394	1·220
1952	177	11 h 56 min	14·96	98	4·399	1·221
1953	184	11 h 37 min	15·83	100	4·056	1·126
1954	197	11 h 34 min	17·03	106	3·965	1·101
1955	198	11 h 34 min	17·10	117	3·880	1·077
1956	202	11 h 20 min	17·83	111	3·866	1·073

CONTINUOUS WASTE-GAS ANALYSIS

Open-hearth operators have long realized that a deficiency of combustion air can result in damage to the furnace refractories, and that an excess of combustion air adversely affects fuel consumption and heat time by decreasing the flame temperature. As a result, modern furnaces are equipped with fuel/air ratio control systems. Although the use of fuel/air ratio controllers has substantially improved the uniformity of combustion conditions within the furnace, there remains considerable variation in air input caused by differences in infiltration in the opposite ends of the furnace, and considerable variation in air demand resulting from changes in the rate of evolution of carbon monoxide from the bath.

Thus, regulation of the fuel/air ratio can only partially achieve control of combustion conditions prevailing within the furnace chamber. Since the objective is control of the analysis of the waste gas, the variations in the waste-gas analysis should obviously actuate the control system. To be practical, a control system must be continuous, rapid, and accurate. Such equipment and instruments have been available for several years, but their use in the open-hearth had to await the development of a durable device for continuously sampling the hot waste gases. Research and development work on this problem has quite recently brought forth a simple and rugged device that can withstand long-time exposure to the hot waste gases in the downtakes of an open-hearth furnace.

The availability of a reliable gas sampler now permits the interlocking of the analytical instruments with the air input fans and thereby achieves nearly perfect control of the oxygen in the waste gas. Figure 2 shows the oxygen content of the waste gas over a 24-h period on the same furnace for three different



(a) Manual control (b) Fuel/air ratio control (c) Continuous oxygen analysis control

Fig. 2—Oxygen content of waste gas

Table IV

EFFECT OF OXYGEN CONTROL ON FURNACE PERFORMANCE

	Test Furnace	Shop Average	Improvement, %
Heat weight, net tons	266·7	271·9	...
Tap-to-tap time	9 h 30 min	10 h 10 min	7·0
Fuel consumption, 10^3 B.t.u./net ton	3·304	3·561	7·2
Average roof life, heats	136	118	15·2
Average frontwall life, heats	119	102	16·7

conditions: (*a*) with the air and fuel controlled manually, (*b*) with fuel/air ratio control, and (*c*) with continuous oxygen analysis control.[5] Under the first two conditions, the oxygen recorder showed that the waste gas varied within a few minutes from an absence of oxygen, or reducing conditions, to an excess greater than 10% oxygen. Compared with these two conditions, the third chart shows nearly perfect control of the oxygen content of the waste gas at a level of 2–3% for the entire 24-h period.

The benefits obtainable when operating with controlled waste-gas analysis were demonstrated recently by a five-month trial at the Geneva Works of the Columbia–Geneva Steel Division of the United States Steel Corporation. The results of this test, as shown in Table IV, were so favourable that this shop is now proceeding with the installation of oxygen controllers on all furnaces and initial trials on individual furnaces are being made in a number of other open-hearth shops.

CHARGING AND REFINING

A better understanding of the importance of all factors from the selection of raw materials to the charging of the open-hearth furnace and the manipulation of the slag to obtain maximum overall production at a high level of quality has been increasingly evident in recent years.

The variety of pig-iron analyses used in various locations in the U.S.A. are shown in Table V. The types of ore available in southern and western states account for the high phosphorus content of the pig irons, whereas the phosphorus content of northern and eastern pig irons is in part due to the recycling of open-hearth slag through the blast-furnaces. The increase in percentage of pig iron in the charge which has occurred in the plant of United States Steel Corporation, as shown in Table VI, is typical of the industry. During this period, the amount of phosphorus charged in the open-hearth increased by over 80% as the result of increased pig-iron usage, together with a higher average percentage of phosphorus in the

Table V

TYPICAL ANALYSES OF U.S. BASIC PIG IRONS

Location	Si, %	S, %	P, %	Mn, %
Eastern	0·70	0·035	0·388	0·49
Western	0·90	0·045	0·409	0·14
Southern	0·84	0·046	0·800	0·35
Northern	1·62	0·029	0·282	2·28

iron. At the same time, not only did the silicon in the charge increase proportionately with the pig iron, but also larger ore charges with additional silica were necessitated. The accompanying reduction in limestone consumption as shown in Fig. 3 for United States Steel Corporation plants reflects the progress made in furnace charging and slag manipulation during this period. The use of limestone decreased from an estimated 256 lb per ton of ingots in 1932 to about 162 lb in 1937, and, following a period of little change, has decreased since 1950 to about 125 lb/ton in 1956. In the years of high limestone consumption, little attention was given to proper maintenance of the flush hole, and so the quantity of flush slag varied greatly and the limestone was often not properly covered and came up into the slag before the flush slag was removed. In contrast, many furnaces are today equipped with the preferred front flush holes, and in many cases, with both frontwall and backwall flush holes, and great care is exercised to maintain control over the quantity of flush slag removed.

As a result, large proportions of the phosphorus, sulphur, and silica are removed in the flush slag, less limestone is required, and, with the smaller slag volume, the slag may be manipulated more readily; time of heat is improved with reduced fuel consumption, and control of phosphorus and sulphur in the finished steel is more easily exercised.

Lack of control of the carbon content of the bath at melt has long been recognized as contributing to low production rates and inferior steel quality. Today, practically all open-hearth shops exercise some method of melt-in control; seldom if ever are they the same in each shop.

DESILICONIZATION

Desiliconizing of hot metal is not general practice in the operation of open-hearth furnaces in the U.S.A. There are in operation, however, 22 large tilting furnaces using fully blown metal in a duplex operation in conjunction with acid Bessemer converters.[1] Such furnaces are extremely fast, producing 175–200-ton heats in 3–4 h. In addition, there are 36 large stationary furnaces which use blown metal as a part of the charge. The use of rolling scale for desiliconization has been practised to a limited extent[6] but the overall results have not justified the adoption of this practice. The simplest procedure for desiliconizing hot metal is the direct injection of oxygen, but the fume problem created by this operation is too severe to permit its adoption without the installation of fume-collecting devices.

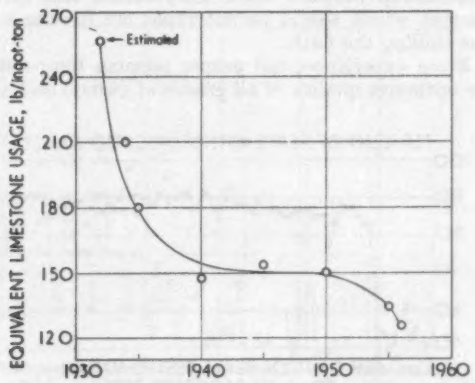


Fig. 3—Limestone consumption in plants of the United States Steel Corporation

Table VI

PIG-IRON USAGE IN PLANTS OF UNITED STATES STEEL CORPORATION

Year	Pig Iron in Open-hearth Charge, %
1934	51·2
1939	59·1
1944	60·7
1949	61·4
1954	61·9
1955	62·3

SULPHUR CONTROL

Even under the most favourable conditions, the basic open-hearth furnace is poorly suited for desulphurization, since unmelted scrap can absorb sulphur from the flame, the high oxygen potential of the slag and metal suppresses the desulphurizing reaction, and there is a relatively low degree of turbulence and intermixing of the slag and metal phases. Can there be any doubt that the most effective method of controlling sulphur in the open-hearth is to permit the least possible amount to enter the system?

If low-sulphur steels are to be produced, the acceptable limit for the sulphur content of liquid fuels appears to be about 1·0%, since below this level excessive sulphur pickup by the scrap is not likely to occur in furnaces using over 50% hot metal. Gaseous fuels such as natural gas and coke-oven gas should have similar limits placed on their sulphur content. Fortunately, natural gas available to open-hearth furnaces in the U.S.A. is practically sulphur-free, and its use as a primary fuel may result in the removal of up to 0·020% sulphur from the metal. On the other hand, coke-oven gas produced from some U.S. coking coals contains over 500 grains of sulphur per 100 ft^3, which on a calorific basis is equivalent to fuel oil containing 2·5% sulphur. Consequently, several steelplants in the U.S.A. using coke-oven gas as their principal fuel are now removing about 90% of the contained sulphur from the gas before it is used in the open-hearth. When using large quantities of desulphurized coke-oven gas (up to 70–80% of the total fuel consumption), it has been found that low-sulphur steel can be produced readily and that furnace productivity can be increased substantially.

Even when low-sulphur fuels are available, the open-hearth operator can be plagued by high-sulphur hot metal. The obvious need for low-sulphur iron has stimulated research and development work toward finding a practical, simple, and low-cost method for desulphurization. For various reasons it is not practical in the U.S.A. to use soda ash for desulphurizing hot metal, the common practice in many European steelplants. The use of special treating vessels as

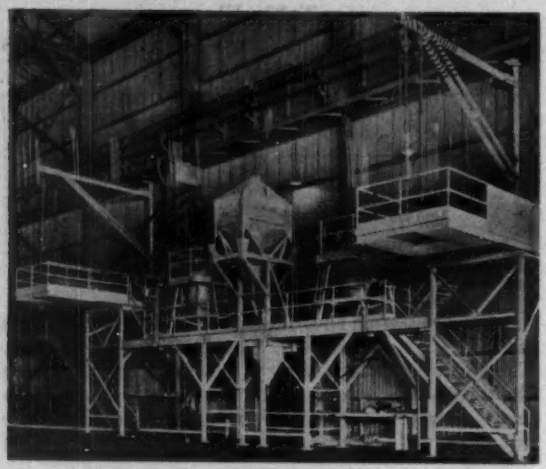


Fig. 4—Desulphurization station, Fairless Works

proposed by Kalling[7] in his rotating vessel, and Trentini[8] in his bottom-blown converter, may achieve nearly complete desulphurization of the pig iron by the use of substantial quantities of desulphurizers. However, the investment cost for special equipment, the maintenance and operating cost, the space limitations in many plants, and the problems and losses involved in rehandling the metal have prevented these processes from being utilized. A method which has found more favour uses a fluidized injection technique whereby the desulphurizer can be blown into a ladle of molten iron at the blast-furnace casthouse or at some convenient site on the way to the open-hearth.[9] Large-scale tests with this rather simple equipment have demonstrated that the desulphurizing agent can be easily transported through pipes and tubes as a dense phase using nitrogen as the carrier gas, for as much as 3 lb of desulphurizer can be carried by 1 ft³ of nitrogen gas. Experimental work with soda ash, burnt lime, calcium carbide, and calcium cyanamide showed that any of these materials could be used with the fluidized injector. Because of local conditions, calcium carbide and calcium cyanamide have been used most extensively.

The operation involves immersing a graphite tube into the top of a ladle of hot metal and then continuing to blow until the desired amount of desulphurizer has been injected, which permits the processing of 5–10 tons of hot metal per minute. Three plants are equipped to treat any cast of hot metal that contains more than 0·050% sulphur; one such installation is shown in Fig. 4. Experience at one plant on treating over 50,000 tons of hot metal showed that the extent of desulphurization when using calcium carbide could be expressed by the equation

$$\% \text{ sulphur removed} = 0{\cdot}009 \times \text{lb } CaC_2/\text{ton} - 0{\cdot}016$$

The equation for calcium cyanamide has not been established but it is known to be practically the equivalent of calcium carbide. Experimental work with burnt lime indicated it to be about half as effective as carbide. The results with burnt lime are

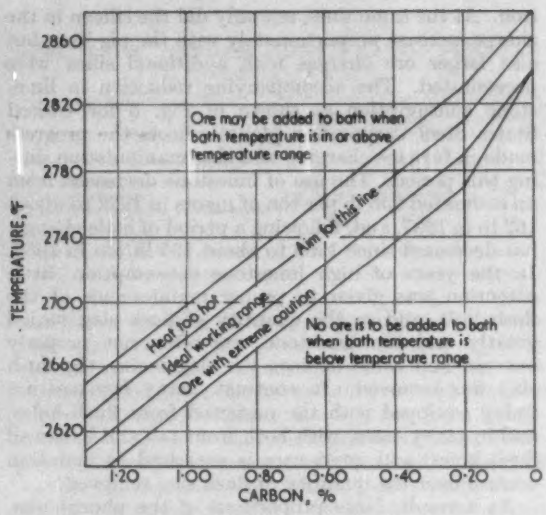


Fig. 5—Oreing schedule for heats to tap at various carbon contents

in fair agreement with the results of Trentini, Wahl, and Allard,[8] who injected lime into a bottom-blown converter at far higher feed rates considering the relative volumes of metal.

TEMPERATURE CONTROL

The development of a reliable and reproducible Pt/13%Pt–Rh bath-immersion thermocouple has resulted in its almost universal routine use, with most shops having installed permanent recording equipment.

At first, most plants confined their efforts to recording bath temperatures just before tapping or furnace deoxidation. However, open-hearth operators and metallurgists soon recognized that the bath-immersion thermocouple could be a valuable tool for controlling bath temperatures within a prescribed range, so that furnace banks and bottoms would not be damaged by getting heats too hot, and excessive ladle skulls could be minimized by avoiding cold heats. Control charts, as shown in Fig. 5, were established showing the relationship between bath temperature and carbon content which would permit rapid ore feeding without chilling the bath.

From experience, the proper tapping temperature for optimum quality of all grades of carbon and alloy

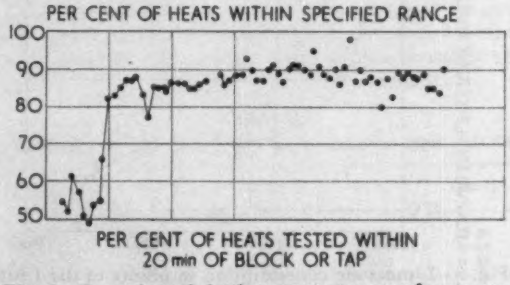


Fig. 6—Open-hearth bath temperature performance

Fig. 7—Effect of banding on thermal cracking of 13¾-in. nozzles (side view)

steels has been established, and an effort is made in plants of the United States Steel Corporation to tap all heats within a range of ± 15° F (± 9° C) of the prescribed temperature. It is found that, with proper attention, all plants can tap at least 80% of their heats within the specified temperature range, and some shops consistently achieve 90% compliance. Figure 6 shows the compliance achieved in one plant and the improvement made in that plant since 1954 when the programme on bath-temperature control was inaugurated. The excellent control of tapping temperatures has been accompanied by a substantial improvement in pouring practice. The control of pouring practice as shown here is especially significant, since these data show the performance in a 14-furnace open-hearth shop, 55% of whose ingot product is high-quality hot-topped and alloy steels. In addition to the improved control of pouring practice, other benefits of tapping-temperature control include a 21% decrease in heats downgraded on account of skulls, and a 22% reduction in stool consumption. Of

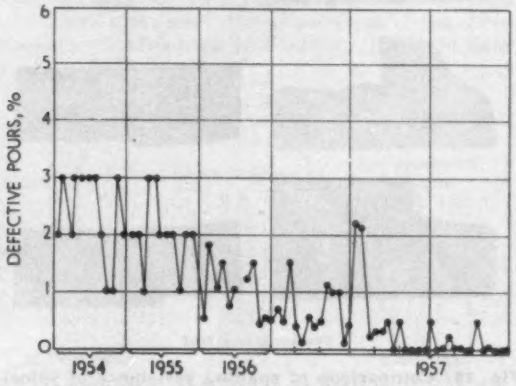


Fig. 8—Open-hearth pouring performance

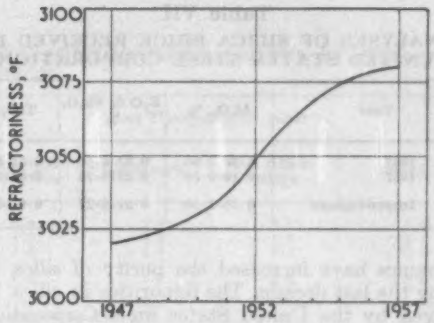


Fig. 9—Average refractoriness of silica brick for indicated year

importance, these improvements in quality have been achieved concurrently with a 7·5% decrease in heat time.

POURING PRACTICE

Fireclay nozzles used for teeming steel tend to develop radial cracks when subjected to thermal shock of the magnitude encountered during filling of a ladle. These cracks extend radially outward from the nozzle bore and become enlarged by erosion from the steel stream as it flows through the nozzle while casting the ingot. Quite frequently the damage becomes so great that a clean dry shut-off of the pouring stream cannot be maintained, and in severe cases there may be complete loss of control of the pouring stream.

Some success has been achieved in improving the resistance of the nozzle to erosion by impregnating the fireclay nozzle with pitch or oil. This practice alters the wettability of the fireclay but does not change the tendency for the nozzle to crack. It has been found (Fig. 7) that the tendency for thermal cracks to widen can be largely overcome by placing two or three metal bands tightly around the outside of the nozzle. Before banded nozzles were used, one shop, as shown in Fig. 8, experienced about 2·0% defectively poured ingots, but during the last part of 1957, when banded nozzles were used as a standard practice, the incidence of defective pours was at the extraordinarily low level of 0·3% of all ingots poured. A clean pour is defined as a stream completely free from even the slightest dribble.

REFRACTORIES

It was not until about 15 years ago that the steel industry started to become aware of the significant correlation between analysis and service performance of silica roof brick.[11]

Laboratory studies showed that the softening point and resistance to deformation of roof brick were related to the silica content and were lowered as the Al_2O_3, K_2O, Na_2O, and TiO_2 content of the brick increased. Open-hearth tests, in which one-half of the roof was constructed of lower-silica, lower-softening-point brick and the other half of high-silica, more refractory brick, demonstrated the superiority of the purer brick. As the result of requests by the steel industry for improvement, the refractories

Table VII

ANALYSES OF SILICA BRICK RECEIVED BY UNITED STATES STEEL CORPORATION

Year	Al_2O_3, %	K_2O & Na_2O, %	TiO_2, %
1947	0·30–2·09	0·03–0·50	0·01–0·16
1957	0·10–0·50	0·02–0·23	0·01–0·08
Improvement	0·20–1·59	0·01–0·27	0·0 –0·08

companies have increased the purity of silica brick during the last decade. The impurities in silica brick received by the United States Steel Corporation in 1947 and in 1957 are shown in Table VII.

As shown in Fig. 9, the average refractoriness of all brands of silica roof brick made in the U.S.A. increased by 60° F (33·3° C) from 1947 to 1957; however, more significantly, the refractoriness of several widely used brands increased as much as 100° F (55·6° C), and 70% of the brick used for roof brick has a softening point over 3050° F.

One of the means developed to combat the general decrease in roof life with higher production rates is the so-called 'zebra roof,' in which partial rings of basic brick are alternated with silica brick rings in those roof areas subject to the greatest wear.[12] Since its inception in 1949, about 35% of the shops in the U.S.A. have found that roof life and furnace availability are sufficiently improved to justify the additional refractory cost. Refractory consumption with zebra roofs is about 5–6 lb of silica brick and 1 lb of basic brick per ton of steel, compared with 3–3·5 lb of basic brick for an all-basic roof. Since zebra roofs are limited to the temperatures permissible with silica roofs, the future of zebra roofs is questionable, and may be expected eventually to give way to all-basic construction, or, more likely, to all-silica roofs of increased height.

There has been a definite trend throughout the years towards an increasingly wider use of basic refractories to the extent that many furnaces today would require only a basic roof to become all-basic furnaces. As a result of improved basic-brick quality and the use of steel casings, silica brick in backwalls, frontwalls, and endwalls has been practically eliminated. However, much of the increase in basic-brick usage has been associated with the growing use of suspended construction, particularly in the furnace ends; the latest calculation shows that at the end of 1957 there were 254 installations, representing 29% of the basic open-hearths in the U.S.A. Many of the suspended ends were initiated by the recent trend to increase heat size by hearth extension, a practice which often necessitates reducing the uptakes to the point where narrow single uptakes with suspended chill walls become mandatory.

In recognition of the superiority of magnesia as a basic refractory, a search was made for a new type of high-magnesia brick that would not be limited in its application by the spalling sensitivity characteristic of existing commercial magnesite brick. The result was a spinel-bonded periclase brick, which in laboratory tests showed (Fig. 10) excellent spalling resistance. This brick has given promising performances in the exposed walls of both open-hearths and electric furnaces and will soon be given trials in open-hearth roofs.

ALL-BASIC FURNACES

Possibly the continuing reappraisal of comparative construction costs and operating performance of silica and basic brick offers some explanation of the slow adoption of the all-basic furnace in the U.S.A. There can be little doubt that improved silica-brick quality, improved combustion practices, and extended hearths have combined to improve operations so that interest in the potentialities of the all-basic furnace has been somewhat dampened. Nevertheless, the incentive for better performance continues with the recognition that the improvements made in furnaces with silica roofs can be incorporated in the all-basic

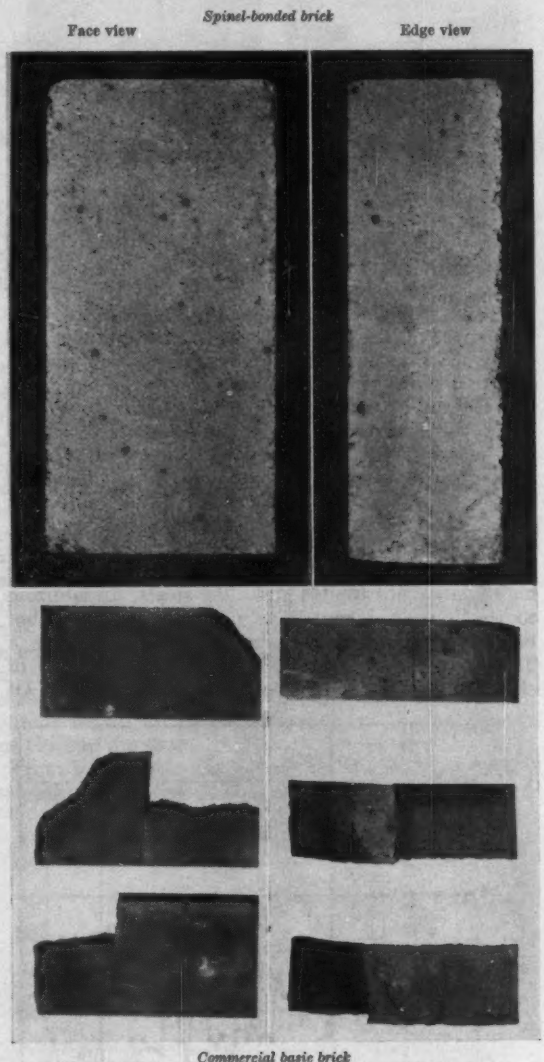


Fig. 10—Comparison of spalling resistance of spinel-bonded and commercial basic brick

Table VIII

OPERATING DATA FOR NO. 10 ALL-BASIC FURNACE, SOUTH WORKS, UNITED STATES STEEL CORPORATION

Campaign	Heats Per Unit Roof	Melting Rate Increase of No. 10 Over Shop, %	Fuel Usage Increase of No. 10 Over Shop, %	Lost Time per Heat, min*			
				Bottom Banks and Taphole	Brickwork	All Other Delays	Total
11	229	9·4	4·4	0·0	− 3·4	− 5·1	− 8·5
12	255	9·6	1·6	− 1·8	− 4·5	− 5·8	− 12·1
13	299	10·6	4·8	− 1·9	− 4·9	− 3·9	− 10·7
Average of thirteen campaigns	238	13·0	4·8	1·1	− 3·7	− 2·9	− 5·5

* Minus values are shorter times for No. 10 over other furnaces.

furnace with its productivity advantage. Currently, eight companies are operating a total of 15 all-basic furnaces with at least three more to be built in the near future, whereas only one all-basic furnace was in operation from 1947 to 1954. Of the operating furnaces, nine have flat suspended roofs, two have radially suspended curved roofs, and four have sprung roofs, highlighting the fact that the search for the optimum basic-roof design is far from ended. Recent sprung-roof trials reflect a hope that this simplified construction may lower the initial installation and refractory costs sufficiently to provide the needed economic incentive for all-basic construction.

Of interest are several installations of fused and cast basic brick in sprung arch roofs.[13] These bricks are very expensive but have been reported to be showing good durability and arch stability.

The longest experience with an all-basic furnace in the U.S.A. has been obtained at No. 10 furnace in the No. 2 open-hearth shop at the South Works of the United States Steel Corporation in Chicago, Ill.[14] The first basic roof was installed in June, 1947, and the furnace is now in its fifteenth operating campaign. During this period, many changes have been incorporated, including various designs of uptakes, port ends, and roofs; many different types of basic brick have been used for roof and furnace ports, several types of fuel burners have been used, and different firing rates have been tried.

One of the principal advantages of the basic roof is the higher productivity and lower delay time for repairs. The all-basic furnace at South Works, tapping about 130 tons per heat, produced a yearly average of 9732 tons more steel than the average of the other furnaces with silica roofs in the shop. Pertinent data recorded for the last three furnace campaigns and the averages for the 13 campaigns are shown in Table VIII. The melting rate of the all-basic furnace exceeded the silica furnaces in the shop by 13%, whereas the fuel consumption has averaged 4·8% higher.

There can be little doubt that the growing interest in the all-basic furnace will stimulate accelerated efforts to arrive at optimum design and operating conditions.

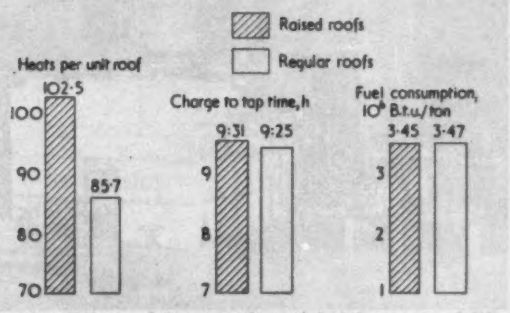


Fig. 11—Effect of increased roof height on roof life, heat time, and fuel

INCREASED ROOF HEIGHT

A study in open-hearth design which promises to be productive suggests the possibility of improving roof life without any sacrifice in fuel consumption or in

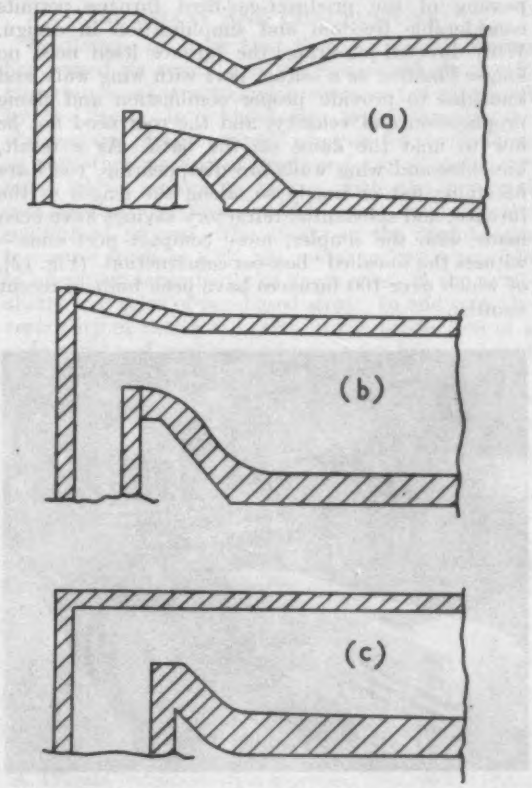


Fig. 12—(*a*) Knuckled roof, 1925; (*b*) sloped port roof, 1950; (*c*) box-car roof, 1958

Table IX

COMPARISON OF BASIC MONOLITHIC MATERIALS

Composition, %

Year	MgO, %	Al_2O_3, %	Fe_2O_3, %	Cr_2O_3, %	CaO, %	TiO_2, %	Na_2O_3, %	B_2O_3, %
1947	79·0	1·4	2·9	None	4·7	9·9	1·6	0·3
1957	93·2	0·6	0·4	1·2	1·0	2·7	0·2	0·6

heat time by increasing the height of the roof.[15] Experiments with roofs raised 3–12 in. at the crown by raising the skewbacks or by increasing the rise of the arch have demonstrated that roof life is improved 8–24%, as shown in Fig. 11. Further studies are now in progress to determine the optimum roof height for maximum overall economy. Conceivably, with current firing rates the optimum roof height may be substantially above that now used, and structural changes on many furnaces now limited in height may be found desirable. The insulation of open-hearth roofs was tried and abandoned many years ago because of the adverse effect on refractory life due to a deeper penetration of iron oxide into the brick with a resultant increased tendency for deep spalling. It will be interesting to determine whether increased roof height will permit insulation with attendant fuel savings without decreased roof life.

The change in roof height is related to other design changes which reflect a belated recognition that the passing of the producer-gas-fired furnace permits considerable freedom and simplification in design. With directed-jet firing, the furnace itself need no longer function as a burner port with wing walls and knuckles to provide proper combustion and flame propagation and velocity, and the roof need not be low to hold the flame on the bath. As a result, knuckles and wing walls are disappearing, roofs are becoming flat or nearly so, along the length of the furnace, and substantial refractory savings have been made with the simpler, more compact port ends—witness the so-called ' box-car construction ' (Fig. 12), of which over 100 furnaces have been built in recent months.

BOTTOM CONSTRUCTION

Today, practically all basic furnaces are of pan-type construction with rammed bottoms. Notable among improvements in materials of construction has been the use of higher-purity magnesite; the magnesia content of ramming materials has increased 14% during the past ten years, as shown in Table IX. It is too soon to evaluate the results of several furnaces which have been constructed using three tiers of basic brick without any burned or rammed magnesite on the bottom.[16]

Within the last several years, several furnaces have been built using large carbon blocks on which 12–15 in. of magnesite is rammed. It is claimed that with this type of bottom the limestone is calcined faster and the heat is transferred faster to the scrap. In view of the difficulties which may be encountered due to oxidation when carbon blocks in blast-furnaces are exposed to moisture or air, it will be especially interesting to follow the progress of these installations.

PREFABRICATED OPEN-HEARTH FURNACES

A process unique in the steel industry involves the prefabrication of furnaces outside the open-hearth shop and moving them into position as a complete package.[17] After eight of the open-hearths at the Geneva Works of the Columbia–Geneva Steel Division of the United States Steel Corporation had been rebuilt and enlarged from 240 to 300 tons capacity by the pre-erection of the structural work only, the ninth furnace was completely built outside the shop on the pit level, including all the brickwork and a rammed magnesite bottom. The total downtime on this furnace was 11 days, compared with the normal 25–30 days for a complete rebuild. For the furnaces in

Fig. 13—Installation of prefabricated open-hearth furnace

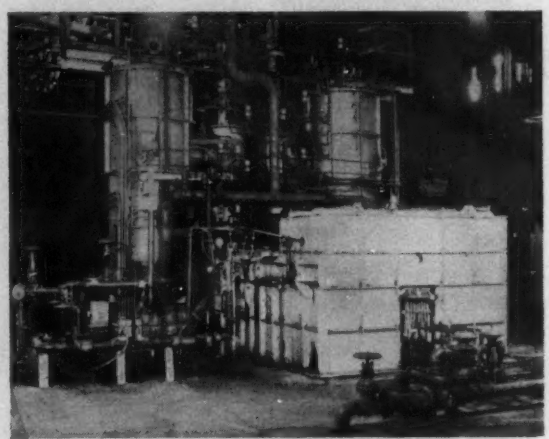


Fig. 14—Hot model open-hearth furnace

which the structural steelwork only was prefabricated outside of the shop, the downtime was about 16 days.

Figure 13 shows the completed furnace weighing 1850 tons after the diesel locomotive had placed it in position for cross-transfer to its foundation columns. It required only 78 min to move the furnace from its erection position outside the shop to its permanent foundation.

CLOSED-CIRCUIT TELEVISION

Experimental installation of closed-circuit television systems have been made on several open-hearth furnaces to evaluate its usefulness for combustion control. The television cameras are mounted just outside each port endwall to provide a view of the flame, bath, banks, walls, and roof. A clear view can be obtained only with the camera sighted in the firing direction, but fair images can be obtained when sighting counter to the flame direction, except when the bath reactions are generating large amounts of fume. These television cameras have been in service for over a year but it is too early to judge what contribution they can make to improved control of combustion, refractory life, and furnace operation.

MODEL OPEN-HEARTH STUDIES

For several years, research workers at the United States Steel Corporation have been studying the effect of design features and firing practices on the operating efficiency of a model combustion unit (Fig. 14) built to a scale of about 1 : 12 of a modern open-hearth.[18] The model is not used to melt steel; instead, calorimeters are placed strategically in the hearth and checker chambers so that heat flow at various locations can be recorded. Before experiments could proceed, it was necessary to establish that the distribution of heat and temperature in the model furnace system were similar to conditions in a prototype operating unit. Thermal similitude is not always compatible with flow similitude, and when in the studies a compromise was required, similitude of flow was sacrificed.

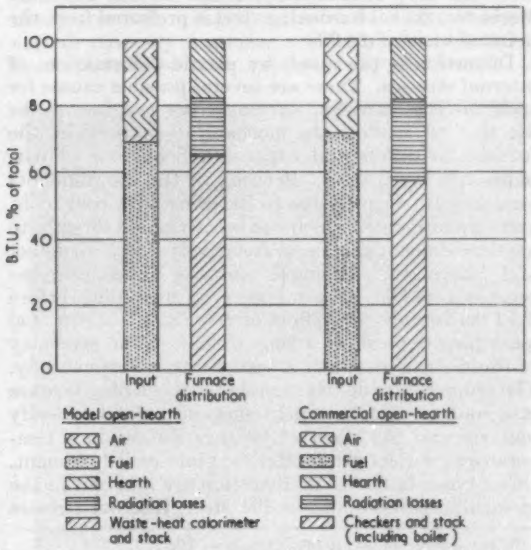


Fig. 15—Comparison of model and commercial open-hearth heat balance

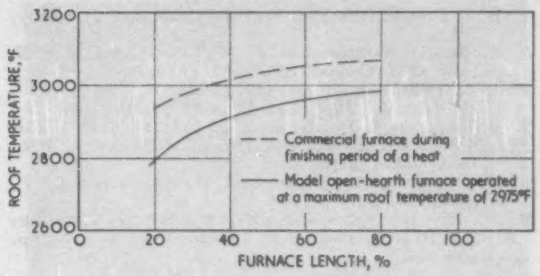


Fig. 16—Roof-temperature distribution, commercial and model open-hearth furnaces

It will be noted in Fig. 15 that when the heat input from fuel and air to the model and the prototype production unit at Fairless Works is similar, radiation losses are somewhat higher in the commercial furnace. Also, the heat passing through the checkers and stack and the heat units absorbed by the respective hearths are similar. While the similarity between the heat balances was designed into the model furnace, the achievement of similar roof-temperature distributions (Fig. 16) indicates that thermal similitude has been achieved.

SUMMARY AND CONCLUSIONS

Predictions of many that the open-hearth process has passed its zenith and will henceforth decline in importance as a steelmaking process are not supported by the facts. In making any predictions on the obsolescence of any process, whether for steelmaking or any other method of producing useful goods, one must never neglect to reckon with the potential technological advances which may improve the established process. The ability of the open-hearth to use as much as 83% hot metal makes it possible to operate independently of fluctuations in the availability and price of purchased scrap. In addition, the versatility of the open-hearth in the production of a wide variety of steel grades has not yet been matched by the newer processes.

It is safe to predict, however, that in the future open-hearth furnaces will be larger, heat times will be shorter, fuel consumption will continue to decline, furnace life will increase—all without sacrificing steel quality. In fact, the results of greater emphasis on flushing practice, sulphur control, temperature control, improved pouring-pit refractories, and pouring-pit practice will be reflected in an improvement in quality, regardless of the size and speed of the open-hearth furnaces.

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A Study of the Distortion of High-carbon High-chromium Die Steels

By K. Sachs, Ph.D., M.Sc.

SYNOPSIS

A significant part of the distortion which may occur in the heat treatment of dies made of high-carbon high-chromium oil-hardening steel is attributed to stresses arising from differences in dilatation due to differences in carbide distribution in adjacent layers of the forged bar. A test is described which reveals the influence of carbide distribution on the susceptibility to distortion. The test is not very sensitive to geometrical causes of distortion and does not reveal any advantage of martempering over oil quenching. Accentuated distortion resulting from a longitudinal temperature gradient emphasizes the importance of an even temperature distribution in the hardening furnace. 1491

Introduction

BLANKING DIES for thin sheet must retain square edges and accurate clearances in order to avoid deformation or burring at the edges of the sheet. Gradual wear of the cutting edges, which necessitates re-grinding and re-setting of the dies, is minimized by the employment of extremely hard steels. Hardness and wear resistance are important in applications where the sheet carries an abrasive scale, e.g. in the stamping of laminations from silicon steels. In this particular case dimensional accuracy is also imperative and practical experience has favoured the use of ' non-distorting ' high-carbon high-chromium oil-hardening steels, tempered for one hour at 200° C, to a hardness of 800 to 850 D.P.N. The dies are machined from fully annealed forged bars or blanks, at a hardness of about 250 D.P.N. If the steel is hardened from the correct temperature the expansion associated with the formation of martensite is balanced by the thermal contraction of the austenite retained in the hardening operation so that heat treatment does not normally produce a change in volume.[1, 2]

Nevertheless, it has been found in practice that distortion sometimes occurs in heat treatment. In many cases, slight distortion is corrected in a final grinding operation but some large dies have been known to distort beyond the grinding allowance and some dimensions, such as the distance between holes, etc., are not amenable to correction by grinding. A distorted die may be annealed and re-machined or it may have to be scrapped, involving losses in expensive steel, toolroom labour, and some re-adjustment of the routine in the production shop.

It is possible to eliminate distortion completely by the use of an air-hardening high-carbon high-chromium steel and a ' balanced ' heat treatment which involves the experimental determination of a tempering temperature which just corrects the dimensional changes due to hardening.[2] Unfortunately the dimensional changes are not usually the same in all directions, so that careful empirical correction of this kind can only eliminate distortion in one direction. Moreover, the oil-hardening steel is preferred from the point of view of die life.

Distortion is the relief, by plastic deformation, of internal stresses. There are several possible causes for such internal stresses, varying from sagging of the die due to inadequate mechanical support in the furnace to differential expansion behaviour of carbides and the matrix. Bending of the die under its own weight, warping due to handling with cold tools, and similar defects which can be attributed directly to heat-treatment practice, are relatively simple to detect and eliminate. Residual stresses from previous processes should be eliminated by annealing before final machining. The effect of vertical or longitudinal quenching depends to a large extent on the geometry of the die and is worth investigating experimentally. The temperature distribution in the hardening furnace in a routine heat-treatment shop may not be ideally uniform and the effect of heating the die in a temperature gradient is a matter for practical experiment. Other possible causes of distortion are inherent in the quenching process and in the steel; internal stresses

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The author is at the G.K.N. Group Research Laboratories, Wolverhampton.

Fig. 1—Distorted ring die after removal of specimens

due to temperature gradients set up during quenching, and due to martensite formation occurring at different times in different parts of the die; internal stresses between different constituents, possibly aggravated by segregation in the steel; and thermal stresses due to differential expansion behaviour of different constituents, particularly carbides and the matrix.

This type of steel contains 2–2·5%C, and 12–13% Cr, and the normal structure reveals chromium carbide drawn out into stringers in the direction of forging in a matrix of lightly tempered martensite, with a small amount of retained austenite. The important part which the carbide in the structure plays in the distortion of the steel is underlined by the observation[1, 2] that hardening causes lengthening in the direction of forging while the dimensions at right-angles show no change or even a slight contraction. The role of the carbide stringers in causing anisotropic dilatations has been underlined and explained by Frehser.[4] In

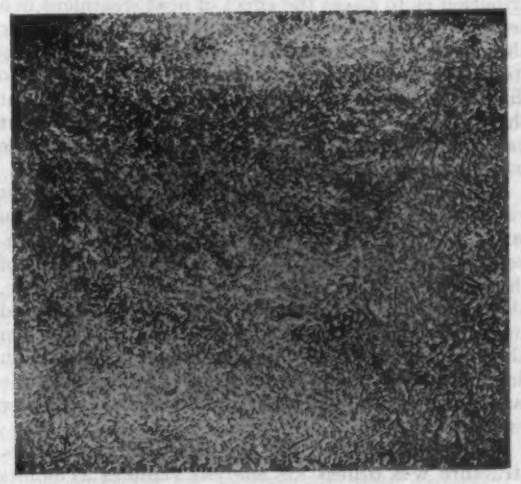


Fig. 2—Cross-section through ring die × 1½

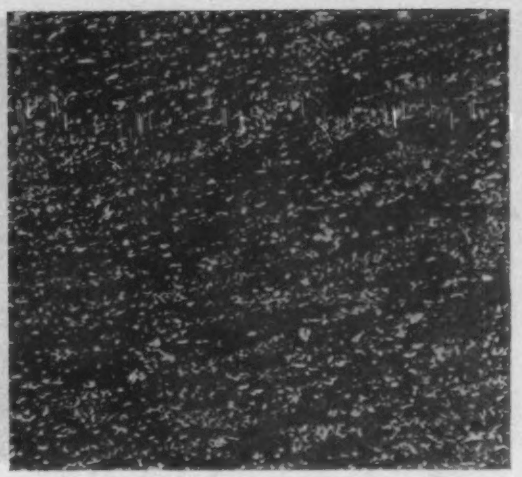


Fig. 3—Carbide distribution near surface of ring die × 90

his view, normal hardening procedure allows the matrix to expand more than the carbide during the slow heating, but in rapid quenching the dilatations of the matrix, e.g. thermal contraction and the expansion associated with martensite formation, are restrained by the carbide 'skeleton,' so that the resultant effect is expansion parallel to the carbide stringers.

The present paper deals with experiments aimed at assessing the relative importance of the different factors which contribute to the distortion of high-carbon high-chromium steels. A distorted die was examined, and a test was developed which reveals the effect of the location of the specimen in the forged bar. The effects of horizontal and vertical quenching, of heat treatment in a temperature gradient, and of different martempering treatments, were studied by means of this test.

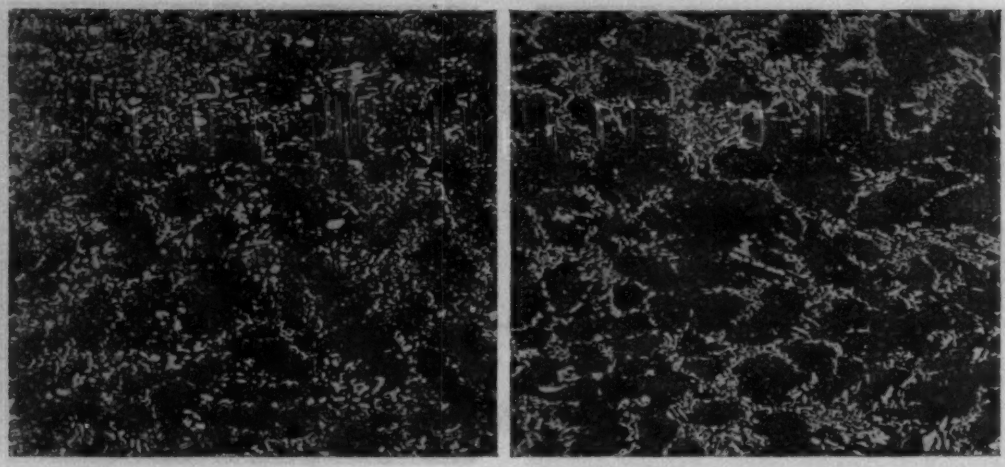
EXAMINATION OF A DISTORTED RING DIE

A ring die, nominal external diameter 10·25 in., had distorted on hardening. It was annealed and returned to its original dimensions. Hardening was attempted a second time and distortion occurred again, although to a lesser extent. After grinding to the nominal outside diameter it was found that two areas on diametrically opposite sides of the ring were not touched by the grindstone i.e. the ring was below size in one direction and had to be scrapped. A detailed examination of this die was made with a view to gaining some insight into the probable causes of distortion. The die, after removal of various specimens, is illustrated in Fig. 1.

External and internal diameters were measured very accurately in four directions round the circle:

External Diameter, in.	Internal Diameter, in.
10·2485	6·949
10·2500	6·959
10·2500	6·959
10·2500	6·958

The hardness was measured at various points on the surface and on the cross-section. The scatter appeared



(a) (b)

Fig. 4—Carbide distribution near centre of ring die × 90

normal and there was no evidence of decarburization. The cross-section, etched for ½ min in 25% ammonium persulphate, is illustrated in Fig. 2. Coarse dendrites are clearly visible. In the centre of the section they are oriented in all directions, but within about ⅜–½ in. of the surface they tend to be parallel to the latter and those dendrites which remain normal to the surface are short and broken up. The ring was machined from a round slab which had been upset by hammer-forging, and the effect of the hot forging had evidently not penetrated very far into the metal. The difference between the surface layers and the centre is shown up very clearly by the distribution of the carbides. Figure 3 illustrates the carbides near the surface in the cross-section, Figs. 4*a* and 4*b* those in the centre in both transverse and circumferential sections. It is evident that the carbides in the surface layer have been broken up and forced into the direction of flow of the metal, while those in the centre have, in large measure, retained their dendritic arrangement.

Samples were taken from the surface and central zones and analysed for carbon and chromium:

	C, %	Cr, %
Shaper cuttings to ¼ in. below surface	2·30	13·51
Drillings to ¼ in. below surface	2·36	13·55
Drillings from ¼ in. to 1 in. below surface	2·34	13·55

The carbon content in the immediate surface layer is slightly lower than in the bulk of the material but the difference is too small to account for the distortion.

The actual amount of carbide in the microstructure at the surface and in the centre of the section is substantially the same and the matrix structures are also similar, consisting of martensite and 20–30% retained austenite. X-ray glancing angle photographs with molybdenum radiation, taken near the surface and the centre of the section, showed that the steel contained roughly 25% austenite. This uniformity of structure confirms that there was no substantial decarburization, that there was no temperature gradient sufficient to cause more carbon to be dissolved in the austenite at the higher temperature, and that the quenching was sufficiently uniform to prevent local transformation or stabilization of the austenite.

DISTORTION TEST

The examination of the distorted die underlined the importance of variations in the carbide distribution in different parts of a component in influencing its distortion behaviour. In order to assess the effect of heat treatment and other variables on the susceptibility of dies to distortion, it was necessary to develop a test which would clearly reveal the influence of carbide distribution. A ' mock-up die ', 12 in. long, 3 in. wide, and 7 in. thick, with a 1-in. wide longitudinal strip cut out of the centre, has been developed as a distortion test piece by Barndt,[2] but this specimen is rather large and awkward to machine. A very useful test which is widely employed in distortion studies uses discs with an eccentric hole tangential to the external diameter[5]; the gap in the circumference of the disc is extremely sensitive to dimensional changes during heat treatment. The test is used for comparing the behaviour of different steels or the effect of different treatments, but it cannot be used conveniently for discriminating between differences in carbide distribution or to assess the effect of heat treatment in a temperature gradient. For the latter purpose a long thin specimen was required; a change in section along its length was expected to increase its sensitivity to distortion, and arrangements had to be made to cut the specimen from forged bar in such a way that variations in carbide distribution played a recognizable part in its distortion.

It was reasonable to suppose that the greatest variations in carbide distribution would be found in larger sections. The largest size of forged bar conveniently available was 2½ in. square. Examination of the macrostructure (Fig. 5) revealed a central core, about ¾ in. square, containing fairly coarse carbide and traces of dendritic carbide distribution, an outer rim about ⅜ in. deep, of very heavily forged material with fine carbide in parallel stringers, and an intermediate layer, also about ⅜ in. deep, with somewhat coarser carbide stringers.

The specimen used for the study of the macrostructure was drilled for analysis samples at points representative of the three distinct zones and was then

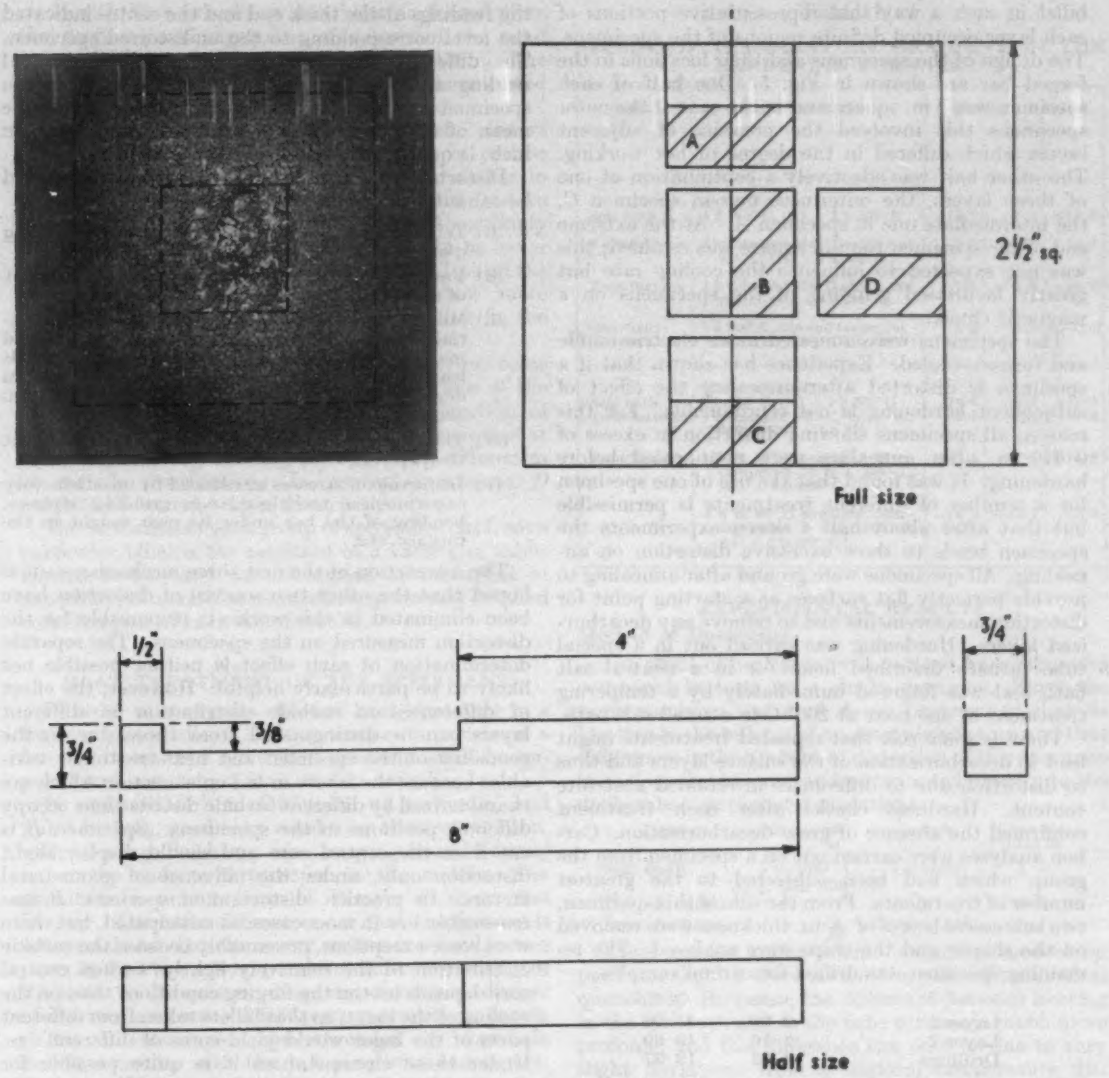


Fig. 5—Distortion specimen and location of specimens in forged bar

oil-quenched from 960° C. X-ray glancing-angle photographs were taken with Co radiation and the line pattern was scanned with a Geiger counter. Owing to the severe internal stresses resulting from the quench the pattern was not very sharp and there was a fairly dense background. The lines were too diffuse for parameter measurements which might have revealed the carbon content of the austenite; no double peak could be detected on the martensite lines. It was possible to compare the intensities of the martensite (110) line and the austenite (111) line and thus to determine the ratio of the two constituents with an estimated accuracy of ± 3%. The amount of chromium carbide in equilibrium with austenite at 960° C can be estimated by interpolation from published isothermal sections of the Fe–C–Cr phase diagram[6]:

Position	C, %	Cr, %	Retained austenite in matrix (X-ray), %	Carbide in steel (equilibrium at 960° C), %	Martensite in steel %	Retained austenite in steel, %
Surface	2·15	12·66	12	12·0	77·4	10·6
Intermediate Layer	2·16	12·78	11	12·2	88·1	9·7
Core	2·19	12·80	9	12·4	88·7	8·9

The differences between the layers, both in composition and in the proportion of retained austenite after normal heat treatment, are very slight and are not likely to make a substantial contribution to distortion.

Specimens of suitable length—8 in. was selected because it corresponded to the zone of uniform temperature in the tube furnace used for hardening the specimens—and ¾ in. square could be cut from the

billet in such a way that representative portions of each layer occupied definite regions of the specimens. The design of the specimens and their locations in the forged bar are shown in Fig. 5. One half of each specimen was $\frac{3}{4}$ in. square and in the case of the outer specimens this involved the presence of adjacent layers which differed in the degree of hot working. The other half was effectively a continuation of one of these layers, the outermost one in specimen *C*, the intermediate one in specimen *A*. At the extreme end of the specimen the full square was retained; this was not expected to influence the cooling rate but greatly facilitated grinding of the specimens on a magnetic chuck.

The specimens were annealed in an electric muffle and furnace-cooled. Experience has shown that if a specimen is distorted after annealing the effect of subsequent hardening is not reproducible. For this reason, all specimens showing distortion in excess of 0·010 in. after annealing were re-annealed before hardening. It was found that the use of one specimen for a number of different treatments is permissible but that after about half a dozen experiments the specimen tends to show excessive distortion on annealing. All specimens were ground after annealing to provide perfectly flat surfaces as a starting point for distortion measurements and to remove any decarburized layers. Hardening was carried out in a special tube furnace described below or in a neutral salt bath and was followed immediately by a tempering treatment of one hour at 200° C in a small salt bath.

There is some risk that repeated treatments might lead to decarburization of the surface layers and thus to distortion due to differences in retained austenite content. Hardness checks after each treatment confirmed the absence of gross decarburization. Carbon analyses were carried out on a specimen from the group which had been subjected to the greatest number of treatments. From the side of this specimen, two successive layers of $\frac{1}{32}$ in. thickness were removed on the shaper and the chips were analysed. The remaining specimen was drilled for carbon samples.

	C, %	Cr, %
Layer 1	2·06	14·08
Layer 2	2·16	13·99
Drillings	2·22	13·97

It is evident that there has been very slight decarburization. Its effect on distortion is diminished by repeated grinding between treatments.

Distortion was measured on the top surface. The specimen was placed on a 4-in. ground parallel on a marking table. A dial gauge supported on a Vernier height gauge with its base on the same marking table was set at zero on one corner of the specimen near the thick end. Two readings, one on each side of the centre line, were taken at each of three positions along the specimen: at the thick end (one reading being the zero setting), the centre (i.e. where the change in section occurred), and at the other end (where distortion had produced the maximum movement). The two groups of readings on each side of the centre line were treated separately in the calculation so that each specimen gave distortion figures which could be averaged for a final value but which served to indicate errors introduced by surface oxide, etc. The mean of the readings at the thick end and the centre indicated the level corresponding to the undistorted specimen. The difference between this mean and the actual reading at the remote end is the distortion of the specimen recorded in the tables of results. Thus the mean of two such differences, in thousandths of an inch, is quoted for each specimen.

Distortion of the specimens during hardening could be caused by the following factors:

(i) Temperature gradients, particularly during quenching

(ii) Variation in the carbon content and the amount of retained austenite in different zones

(iii) Micro-stresses and local distortion due to differential dilatation between carbide particles and matrix; with the carbides ordered in stringers this leads to anisotropic dilatations which will vary in degree with variations in forging deformation across the billet

(iv) The effect of residual stresses from previous heat treatments

(v) Distortion or stresses introduced by unsatisfactory experimental technique, e.g. grinding stresses, bending of the bar under its own weight in the furnace, etc.

The interaction of the first three mechanisms—it is hoped that the other two sources of distortion have been eliminated in this work—is responsible for the distortion measured on the specimens. The separate determination of each effect is neither possible nor likely to be particularly helpful. However, the effect of differences in carbide distribution in different layers can be distinguished from those due to the geometry of the specimen and heat-treatment variables because the layers in the cross-section which are characterized by different carbide distributions occupy different positions in the specimens. Specimen *B* is cut from the central core and should display slight distortion only, under the influence of geometrical factors. In practice, distortion of specimen *B* was reasonably low in most cases, as anticipated, but there were some exceptions, presumably because the carbide distribution in the relatively lightly worked central core depends less on the forging conditions than on the cooling of the ingot, so that billets taken from different parts of the ingot would yield cores of different size. Under these circumstances it is quite possible for zones with profound variations in carbide orientation to be included in specimen *B* and to cause severe distortion.

Specimens *A* and *C* consisted of material from different layers and their distortion was affected by differences in the dilatation of these layers. The general effect of hardening is a slight expansion in the direction of working; if the outermost layer tends to expand more than the intermediate one, specimen *C* which has this layer extending over its full length would have a convex bend, yielding a negative distortion figure, while specimen *A* in which the outermost layer extends over half the length only, would show a concave bend, or a positive distortion. In practice, the distortion of specimen *A* was negative, that of specimen *C* positive, suggesting that the intermediate layer tends to show more longitudinal expansion than the most severely worked material close to the surface of the forged bar. This is in agree-

ment with Frehser's observation[4] that in forged plate the coefficient of expansion is lower and the total longitudinal growth on hardening greater in the centre than at the outside and is probably associated with the coarser particle size of the carbide.

The direction in which specimens *A* and *C* distort makes it appear unlikely that variation in carbon content across the billet is a determinant factor in distortion. Segregation in the ingot would lead to low carbon contents in the surface zones. Accordingly the proportion of retained austenite should be lower near the surface than at the centre of the billet and the surface layers would be expected to show more expansion than the rest, leading to bending in the opposite direction to that found in practice.

A fourth specimen, marked *D*, was taken from some of the billets. It was located near the surface of the billet but cut in such a way that the direction of bending due to the geometry of the specimen was at right-angles to any bending introduced by differences in carbide distribution. In general specimens *D* exhibited relatively slight distortion.

The distortion of each group of specimens cut from a particular billet is the resultant of a variety of interrelated factors and an assessment of the effect of experimental variables required separate and detailed consideration of each set of results.

HEAT TREATMENT OF THE SPECIMENS

In order to study the effect of heat treatment in a temperature gradient, it was necessary to construct a furnace in which a controlled gradient could be imposed and maintained over an 8-in. length.

It consisted of a mullite tube, 2½ in. in dia. and 2 ft 6 in. long, gradient wound over the central 14 in. with 16 s.w.g. Brightray wire, varying from 10 turns/in. at the ends to 5 turns/in. in the middle. The circuit is a modification of Weaver's[7] creep test furnace. The main differences are that the furnace is horizontal and that the centre section is wound in two parts so that there is no potential difference at any of the joints in the split winding; thus there is no danger of sparking and no need for larger gaps at these joints.

The thermocouples are threaded in four-hole insulator beads, with the hot junctions 4 in. apart; they can slide in a mullite sheath so that the temperature at any point along the 8-in. heat-treatment zone can be recorded. When the controls were set for uniform temperature the temperature variation over the 8-in. zone could be held down to 3° C; better results might be anticipated from a furnace with a longer winding. The same accuracy was maintained in treatments with temperature gradients of 20° C and 50° C over the 8-in. specimen; steeper gradients were more difficult to control and could not be consistently reproduced in treatments on different specimens. The rather wide fluctuation with time was not thought likely to affect the distortion in heat treatment. Although the tube diameter was just large enough to take all the specimens at once, the heat capacity of the furnace was so low that the removal of a specimen for quenching affected the temperature considerably and it took some time to settle down again; the specimens were therefore hardened separately.

Table I

EFFECT OF TEMPERATURE GRADIENT IN THE HARDENING FURNACE

Furnace	Heat Treatment	Distortion, 0·001 in.		
		A	*B*	*C*
	Billet AAK			
Salt bath	1 h 960° C, OQ + 1 h 200° C	−13·9	+1·8	+12·5
Tube furnace	1 h thin end 985° C, thick end 935° C, OQ + 1 h 200° C	−2·0	+17·1	+24·7
Tube furnace	1 h thin end 935° C, thick end 985° C, OQ + 1 h 200° C	−2·5	+2·8	+18·7
Gas-fired furnace	1 h 960° C thin end facing furnace door, OQ + 1 h 200° C	−6·6	+5·5	+22·5
	Billet ADX (B)			
Salt bath	½ h 960° C, OQ + 1 h 200° C	−14·0	+3·7	+12·3
Tube furnace	1 h thin end 935° C, thick end 985° C, OQ + 1 h 200° C	−3·5	+8·0	+14·4
Tube furnace	1 h in 50° C gradient, Martempered 10 min 200° C, AC, + 1 h 200° C	−13·8	+7·9	+16·8
	1 h in 50° C gradient, Martempered 5 min 280° C, AC + 1 h 200° C	−16·0	+12·7	+22·3

EXPERIMENTAL RESULTS

Method of Quenching

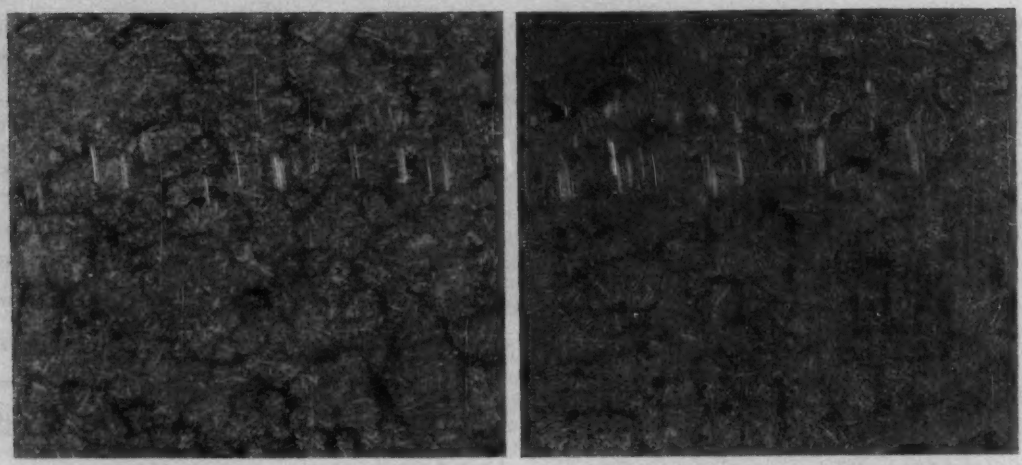
The effect of horizontal and vertical quenching was compared in tests on a single specimen. Since the same specimen was used it can be assumed that its location in the billet is of no great significance and that differences in the amount of distortion of this specimen in various treatments can be attributed directly to the deliberate experimental variations.

Furnace	Treatment	Quench	Distortion, 0·001 in.
Salt bath	½ h, 960° C, OQ, 1 h, 200° C	Vertical	1·4
Tube furnace	,,	,,	6·4
Tube furnace	,,	Horizontal	8·1

These results indicate that horizontal quenching produces slightly more severe distortion than vertical quenching. However, the difference between heating in the salt bath and in the tube furnace is much more profound and this difference can only be due to very slight deviations from a uniform temperature distribution in the tube furnace. It would appear therefore that the difference between horizontal and vertical quenching is so slight as to be unimportant in the case of the specimens used in this work. Larger specimens with greater changes in sections might show greater effects. Apparently the specimen is not very responsive to factors which depend on geometry for their effect. This conclusion will be of importance in the interpretation of the results of other experiments.

Effect of Carbide Distribution

The influence of the structure of the steel, particularly of the distribution of the carbides in different parts of the forged bar, is revealed by the distortion of a group of specimens cut from a single bar according to the scheme shown in Fig. 5. The specimens were oil quenched from the salt bath. Specimen *B* showed very little distortion (0·0018 in.) while specimens *A* and *C* warped 0·0139 in. and 0·0125 in. in opposite



(*a*) Carbide in cold end (935° C) × 90 (*b*) Carbide in hot end (985° C) × 90

Fig. 6—Gradient hardened cast distortion specimen (128*B*) containing 0·97%C, 0·72%Si, 0·73%Mn, and 2·94%Cr

directions. It can be inferred that the carbide distribution in the core of the billet (specimen *B*) was sufficiently uniform for the distortion to be caused by the geometry of the specimen alone; the amount of bending is substantially similar in specimens *A* and *C* which suggests that their distortion is due to the differences in carbide distribution only and that geometrical factors make very little contribution.

Similar behaviour was found in specimens cut from other billets, except that specimen *B* sometimes showed a little more distortion; the bending of the outer specimens in opposite directions can be regarded as a characteristic feature of the test.

Effect of Temperature Gradient

The same specimens were heat-treated in the tube furnace with a temperature gradient of 50° C. The experiment was carried out twice, with the temperature gradient in opposite directions. The distortion measurements are compared in Table I with the figures for specimens hardened in the salt bath and in a gas-fired furnace.

The effect of quenching from a salt bath has already been described. Hardening in a temperature gradient falling by 50° C from the thin end to the thick end results in a profound change in the distortion behaviour. The distortion of specimen *B* is now considerable, that of specimen *C* has been virtually doubled, and specimen *A* shows very little bending, the negative distortion of 0·013 in. being brought back to only 0·002 in. The results suggest that a positive distortion of 0·012 in. to 0·015 in. has been imposed on all the bars by this treatment and this can reasonably be attributed to the temperature gradient. Quenching from a similar gradient in a reverse direction has an effect similar in kind but less pronounced in extent; in particular, the distortion of specimen *B* is slight and the additional positive distortion of specimen *C* is less than in the previous experiment. There can be no doubt, however, that this gradient has also superimposed an additional distortion on the specimens although this additional positive component varies more widely from specimen to specimen than in the previous experiment. After quenching from a works' gas-fired furnace the distortion is intermediate between the results obtained in the laboratory experiments; a similar positive distortion component is present and it can reasonably be attributed to a temperature gradient in the furnace. A temperature survey of the gas-fired furnace showed that there was in fact a gradient of about 50° C over 8 in. from the back to the front of the hearth.

The temperature gradient may increase distortion by imposing a gradient of quenching stresses or transformation stresses; by causing more carbide to go into solution at the hot end it may influence the carbide distribution and increase the stability of the austenite. Quenching stresses are not likely to play a predominant part in the distortion of specimens which are relatively insensitive to geometrical factors. In order to confirm this experimentally, entirely ferritic and entirely austenitic distortion specimens free from carbides were prepared. A Japanese electrolytic iron and an austenitic steel (0·13%C, 0·93%Si, 1·94%Mn, 8·57%Ni, 18·74%Cr) were cast to the shape of the standard distortion specimen, annealed, ground flat on the measuring faces, and hardened in a 50° C temperature gradient. The measured distortion indices, + 1·0 for the ferritic specimen and — 1·7 for the austenitic one, show that distortion due to thermal stresses alone is negligible and that transformation stresses are likely to be of predominant importance.

The effect of transformation in the absence of carbides was studied on similar cast distortion specimens of suitable analysis. One melt (128*B*) contained 0·97%Cr, 0·72%Si, 0·73%Mn, and 2·94%Cr; in the ternary system[6] austenite at 960° C is saturated with Cr_7C_3 at 1·04%C and 3·6%Cr. The presence of Si and Mn may modify the exact equilibrium compositions and a little carbide is in fact present. Figures 6*a* and 6*b* show the amounts in the cold and hot ends respectively; rather more carbide has gone into solution at 985° C than at the lower temperature. The quantity of carbide is much less than in the normal die steel (cf. Figs. 3–5).

The other melt (139*B*) had the composition:

0·54%C, 1·16%Si, 0·82%Mn, 1·43%Cr, and was well within the austenitic field; no carbide was found in the structure. The distortion test results are summarized and compared with the results of similar experiments on test pieces cut from forged bar (Table I) in the table below:

Melt No.	Thick End at 985° C			Thin End at 985° C		
	Distortion Reading					
128*B*	−13·2	−18·1	−20·4	−8·0	−10·7	−15·0
139*B*	+5·7	−12·3	−12·3	+10·9	+0·2	−3·0
Billet No.	Distortion Component due to Temperature Gradient					
AAK	+11·4	+1·0	+6·2	+11·9	+15·3	+12·2
ADX (*B*)	+10·5	+4·3	+2·1			

The distortion component due to the temperature gradient was derived from the figures in Table I by subtracting the distortion readings obtained after hardening at a uniform temperature from those corresponding to the gradient treatments. The temperature gradient has produced roughly the same degree of distortion in both the carbide-free specimens and the specimens cut from forged bar, but they are warped in opposite directions.

In order to establish the role of austenite experimentally, a number of specimens were re-hardened from the gradient furnace, this time without subsequent tempering. X-ray examinations were carried out at three positions along each specimen, using the techniques already described. The proportion of retained austenite in the matrix (i.e. the austenite/martensite ratio expressed as a percentage) is given in the table below:

Specimen Cut from forged bar	Hardening Temperature 985° C	960° C	935° C
	Austenite, %		
ADX (*B*) *A*	22	16	13
ADX (*B*) *B*	29	17	11
ADX (*B*) *D*	18	16	16
Cast Specimen (carbide-free)			
128 *B*	7	trace	0
139 *B*	0	0	0

In specimens cut from forged bar the variation in the proportion of retained austenite with the temperature gradient is consistent and substantial. In the carbide-free specimens there is no retained austenite, and in the specimen on the saturation boundary of austenite, some austenite was retained at the hot end and perhaps in the middle but none at the cold end. It is reasonable to conclude that the variation in the amount of retained austenite is not a predominant cause of the observed distortion.

Hardening from a temperature gradient causes distortion quite distinct from that due to other causes. Distortion occurs with or without chromium carbides or retained austenite in the structure, but not in the absence of the α–γ transformation.

Specimens with carbide stringers and a gradient of retained austenite show positive distortion, while those with neither carbide nor austenite exhibit predominantly negative distortion. The expansion associated with the formation of martensite is diminished by the retention of austenite and greatly inhibited by the carbide 'skeleton'[4]; it is not unreasonable that the transformation stresses should be greatly modified by these effects.

The outstanding factor which appears to determine the tendency to distort due to temperature gradient is the transformation stress. In quenching a bar from a gradient furnace, the M_s temperature will be reached first at the cold end and the martensite transformation then travels along the bar. This can well account for distortion of the specimen and the experiments have shown that it is the principal cause.

The Effect of Martempering

The effect of the geometry of a component on distortion in heat treatment depends to some extent on the temperature gradient during the transformation of austenite to martensite. This gradient can be reduced by martempering and a considerable amount of experimental work was carried out to examine the effect of various martempering treatments. The possibility of eliminating the effects of a temperature gradient in the hardening furnace by equalizing the temperature distribution prior to martensite formation in a martempering bath was obviously worth examining and the experiment was carried out on specimens cut from a billet which had been specially forged on a 3¼-ton hammer. A fresh batch of specimens was used and the results are given in Table I. Quenching from a salt bath gave similar results to those obtained with the other specimens; quenching from a tube furnace with a 50° C gradient produced a positive distortion component as in previous experiments. Specimens heated in a similar temperature gradient and martempered in a salt bath for 10 min at 200° C and for 5 min at 280° C showed somewhat inconsistent distortion behaviour. The additional distortion component due to the gradient was unchanged in specimen *B*, slightly increased in specimen *C*, and completely absent in specimen *A*. The overall effect of martempering was an improvement in the balance between specimens *A* and *C* but an increase in the highest distortion figures obtained. It does not look as though martempering could overcome the problem of distortion due to temperature gradients in the hardening furnace.

Many martempering experiments were carried out with specimens austenitized at a uniform temperature; six different martempering treatments were tried, each one on at least two series of specimens. Their effects were variable and sometimes erratic, but the variations in distortion figures were no greater than random variations which might reasonably be expected. It can be concluded that the specimen used is not sufficiently sensitive to temperature gradients in the cross-section and to geometrical distortion factors generally, for the influence of martempering to be revealed in this test.

CONSIDERATION OF RESULTS

The test employed in this work was designed to bring out effects of the interaction of layers differing in degree of hot working and in carbide distribution. In order to achieve this, the change of cross-section in the test bar had to be relatively small so that the interaction of portions of different cross-section is less profound than in other tests. This accounts for the failure of martempering treatments to reduce the distortion figures and for the negligible effect of

horizontal quenching. The influence of longitudinal temperature gradients, on the other hand, was revealed very clearly in the test and the importance of a uniform temperature distribution in furnaces used for routine heat treatment was underlined.

Factors which may cause distortion were enumerated in the introduction. In the present experiments, thermal stresses and local differences in carbon content and in the amount of retained austenite have been shown to play a minor part. One factor which appears to cause substantial distortion is the transformation stress. It is generally accepted that in components which exhibit considerable variations in cross-section distortion occurs because the light section transforms first; as it expands adjacent parts which are still austenitic yield but when the latter transform and expand in their turn, the ' old ' martensite does not yield and elastic strains are set up, leading to distortion and possibly to quench cracks. In the present work the differences in cross-section were too small to produce much effect, but when a temperature gradient caused the martensite transformation to occur first at one end of the specimen and to travel along it, considerable distortion was observed.

In the absence of a temperature gradient distortion in the test developed in this work is due to differences in expansion characteristics between adjacent layers in the cross-section. It has been shown that there are only slight differences in carbon content and amount of retained austenite between the layers while the degree of hot working and the directionality of the carbide stringers varies substantially. Carbide stringers are known to cause longitudinal expansion in hardening[4] and differential expansion due to differences in carbide distribution may well account for the distortion observed.

CONCLUSION

The warping which still occurs in the heat treatment of a steel which is nominally free from distortion cannot in all cases be attributed to unsatisfactory heat-treatment technique. It is due to an inherent characteristic of the steel, the drawing out of the carbide in stringers parallel to the direction of hot working, and the variations in the degree of hot working through the section of the forged bar. It is possible that modifications in the methods of manufacture of the steel can alter the carbide distribution and further lower the susceptibility of the steel to distortion. The distortion test which was developed for this work seems suitable for investigations of the effects of such modifications.

Acknowledgments

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Criterion for Peritectic and Eutectic Reactions

By Mats Hillert, Sc.D.

SYNOPSIS

The common method of predicting, from the shape of a ternary phase diagram, whether a certain three-phase reaction is peritectic or eutectic is criticized and a new criterion is derived. The relative amounts of the three phases are decisive in some cases but have no influence in other cases. 1516

ACCORDING to the usual definition, a reaction which on cooling can be written $L + \alpha \rightarrow \beta$ or $L + \beta \rightarrow \alpha$ is a peritectic reaction whereas $L \rightarrow \alpha + \beta$ represents a eutectic reaction, where L is a liquid phase and α and β are two solid phases.

The above definition is sufficient for a binary system, but in the case of a ternary system the three phases may change their compositions as a three-phase reaction proceeds and both kinds of reactions should in fact be written $L_1 + \alpha_1 + \beta_1 \rightarrow L_2 + \alpha_2 + \beta_2$. In this case, a eutectic reaction is defined as one where the amounts of α and β both increase when the reaction proceeds, and a peritectic reaction is one where the amount of either α or β decreases. It is apparent that this last definition is somewhat arbi-

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Dr. Hillert is at the Swedish Institute for Metal Research, Stockholm.

trary, since nothing is said about the method of measuring the amounts of α and β. Because of the change in composition there are cases where the weight of a phase increases although the number of moles of the same phase decreases.

This difficulty will not be further discussed here. Instead, the criterion will be examined which is usually used to distinguish between peritectic and eutectic reactions in ternary systems. This is illustrated in Fig. 1 which shows the tie-triangle at a certain temperature, T. The arrows indicate the direction of change in composition of the liquid phase on further cooling. When the arrow points away from the α–β side of the tie-triangle, as in the upper part of Fig. 1, the reaction is said to be eutectic; the amounts of both α and β increase on cooling. The lower part of Fig. 1, on the other hand, represents a peritectic reaction. Here the amount of α decreases on cooling.

In their text books on phase diagrams both Masing[1] and Ricci[2] have discussed cases where this criterion does not hold and more recently Kuo[3] gave another example. The object of the present work was to find the true criterion.

Let us describe the composition of the three phases at a certain temperature by means of an arbitrary, rectangular, coordinate system x, y. The mean composition (x_0, y_0) of a mixture of the three phases is given by

$$x_0 = \frac{n_\alpha x_\alpha + n_\beta x_\beta + n_L x_L}{n_\alpha + n_\beta + n_L}$$

and a corresponding expression for y_0, where n_α, n_β, and n_L denote the quantity of the three phases. This relation holds whether the composition x and the quantity n are expressed as mole fraction and moles or

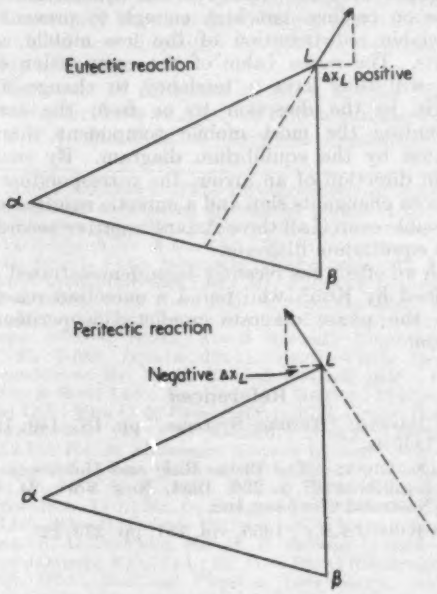

Fig. 1—Illustration of the old criterion for eutectic and peritectic reactions

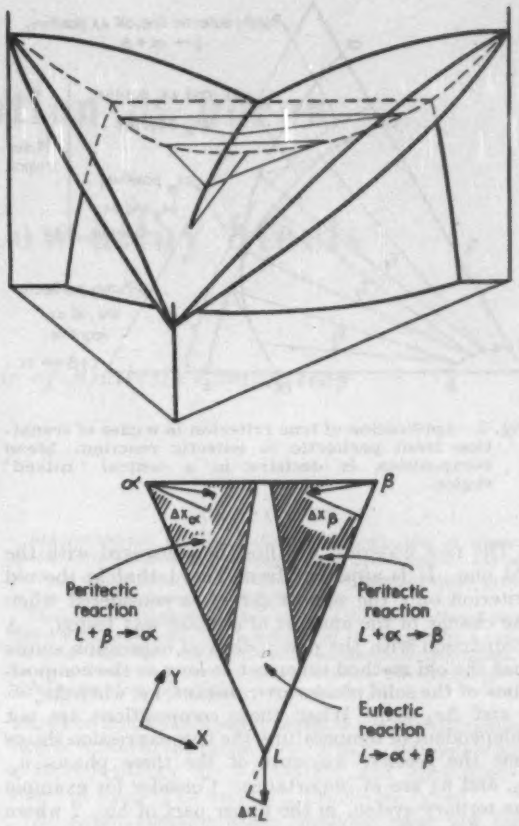

Fig. 2—Application of true criterion in a case usually considered eutectic. Mean composition of specimen is decisive. The reaction is eutectic only if the mean composition lies within the central white region

as weight fraction and weight. The following considerations are thus independent of this choice.

A small change in temperature ΔT will cause a small change in the composition and quantity of each phase but not of the mixture itself.

$$\Delta x_0 = 0$$
$$\Delta n_\alpha + \Delta n_\beta + \Delta n_L = 0$$

and, consequently,

$$n_\alpha \Delta x_\alpha + x_\alpha \Delta n_\alpha + n_\beta \Delta x_\beta + x_\beta \Delta n_\beta + n_L \Delta x_L + x_L \Delta n_L = 0$$

The final result will be especially simple if the coordinate system x, y is chosen in such a way that $x_\beta = x_L > x_\alpha$. It is always possible to do this. A combination of the two last equations then yields

$$\Delta n_\alpha (x_\beta - x_\alpha) = n_\alpha \Delta x_\alpha + n_\beta \Delta x_\beta + n_L \Delta x_L$$

The change of the amount of α-phase on cooling, Δn_α, will thus have the same sign as the expression $n_\alpha \Delta x_\alpha + n_\beta \Delta x_\beta + n_L \Delta x_L$. The change in the amount of β-phase can be tested by the same method but the coordinate system must then be chosen in such a way that $x_\alpha = x_L > x_\beta$. Sometimes it may also be necessary to apply the test to the third phase L, especially if this phase is also solid. A third coordinate system satisfying the condition $x_\alpha = x_\beta > x_L$ must then be used.

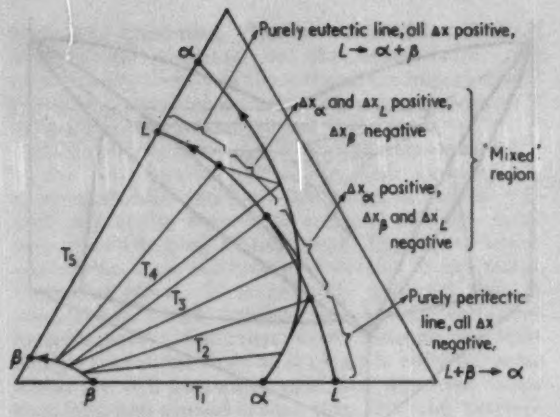

Fig. 3—Application of true criterion in a case of transition from peritectic to eutectic reaction. Mean composition is decisive in a central 'mixed' region

The new criterion will first be compared with the old one. It is apparent from Fig. 1 that in the old criterion only the sign of Δx_L was considered when the change of the amount of α-phase was tested. A comparison with the newly derived expression shows that the old method is correct so long as the compositions of the solid phases are constant, i.e. when $\Delta x_\alpha = 0$ and $\Delta x_\beta = 0$. When these compositions are not independent of temperature, the new expression shows that the relative amounts of the three phases n_α, n_β, and n_L are of importance. Consider for example the ternary system in the upper part of Fig. 2 where two of the binary sides show complete miscibility and the third is of the eutectic type. The declining line extending from the binary eutectic point is generally considered to be a eutectic line. The lower part of Fig. 2 shows the tie-triangle in an isothermal section and the arrows from the three corners indicate the direction and magnitude of the change in composition of the three phases on further cooling by ΔT. A coordinate system has been chosen in order to test the amount of α-phase. Projection of the arrows gives the magnitude of Δx_α, Δx_β, and Δx_L. In this case, Δx_β is negative and the derived expression will thus be negative as soon as the amount of β, n_β, is high enough; the three-phase reaction will then be peritectic. A calculation gives the result illustrated by the shaded regions in Fig. 2. The reaction is eutectic at this temperature only if the mean composition of the system lies within the thin, white region in the middle. The fact that the point, representing the liquid phase, belongs to this region demonstrates that the old and the new criteria become identical when $n_\alpha = n_\beta = 0$.

The new criterion shows that a three-phase reaction always proceeds with an increase of the amount of a certain phase if Δx_α, Δx_β, and Δx_L in the appropriate coordinate system are all positive and with a decrease if they are all negative. This is illustrated by Fig. 3 where the changes in composition during cooling are demonstrated for a ternary system where one of the binary sides shows complete miscibility, one is of the peritectic type, and one of the eutectic type. When the new criterion is used to test the α and L phases, it is found that all Δx are positive for α and negative for L. As a consequence, α will precipitate as L disappears on cooling. A closer examination is necessary for the β-phase. The tie-triangles are therefore shown in Fig. 3 at the three temperatures T_2, T_3, and T_4, where the L–α side is parallel with the direction of change in composition of α, L, and β, respectively. The amount of β-phase decreases, and the three-phase reaction is thus peritectic between T_1 and T_3 for all compositions. Between T_4 and T_5 the amount of β-phase increases for all compositions and the reaction is thus eutectic here. In the intermediate region, T_2 to T_4, the actual composition determines the kind of reaction. According to the old criterion the reaction is peritectic for all compositions in the region T_1 to T_3 and eutectic between T_3 and T_5.

In practice the cooling rate is usually too high to allow equilibrium to be established. It is then very difficult to estimate the relative amounts of the three phases taking part in a certain step of the reaction, even if the mean composition of the system and all the diffusion coefficients were known. As a consequence, predictions about the kind of reaction within a 'mixed' region, like that between T_2 and T_4 in Fig. 3, can seldom be made. A further complication arises from the fact that the three components in a ternary system generally have different diffusion coefficients. A certain cooling rate may be low enough to allow a mobile component to redistribute itself rather well in accordance with the change in the equilibrium conditions on cooling, but high enough to prevent an appreciable redistribution of the less mobile components. The mean value of the composition of a phase will thus have a tendency to change more strongly in the direction to or from the corner representing the most mobile component than is indicated by the equilibrium diagram. By such a shift in direction of an arrow, the corresponding Δx may even change its sign and a eutectic reaction may be possible even if all three Δx are negative according to the equilibrium diagram.

Such an effect has recently been demonstrated and explained by Kuo[3], who found a eutectoid reaction where the phase diagram predicted a peritectoid reaction.

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The Determination of Boron in Carbon and Low-alloy Steels

By the B.I.S.R.A. Methods of Analysis Committee

SYNOPSIS

Absorptiometric procedures for the determination of traces of boron with quinalizarin, curcumin, and dianthrimide, and also methods for the separation of boron from elements usually present in iron and steel, have been investigated.

The method recommended as a result of this work is based on the removal of metal ions from a solution of the sample by a cation-exchange resin and subsequent absorptiometric determination of boron in the eluate by means of dianthrimide. The method gives a high degree of reproducibility and sensitivity. 1518

BORON-CONTAINING STEELS which have been in use for a number of years have not contained appreciable amounts of alloying elements, and boron has been determined by the quinalizarin method.[1] In this procedure, boron is not separated from iron, the only interference of the latter being in the precipitation of ferrous salts in the concentrated sulphuric acid solution used for the colour test.

Although the sensitivity of the method is fairly high, the accuracy obtained is more questionable owing to the very critical dependence of the colour formed on the amount of water present in the sulphuric acid solution at the time of colour development. Since boron in amounts as low as 0·001–0·005% can cause important differences in the mechanical properties of steels, a method of determination to differentiate with certainty between say 0·002% and 0·003%, i.e. capable of reproducibility of ± 0·0002–0·0003%, is highly desirable.

The terms of reference adopted by the Physico-chemical Methods of Analysis Sub-committee* of the B.I.S.R.A. Methods of Analysis Committee were therefore to recommend a method for the determination of boron in the range up to 0·01%, if possible with a reproducibility of ± 0·0002% and applicable to steels of the 3% Cr and 2¼% Cr–Ni–Mo types.

Although spectrographic methods have not been within the scope of the investigation, a spectrographic solution method, at the required level, would encounter similar difficulties to the chemical method in the separation of boron, and direct spectrographic methods ultimately depend on standards which have previously been analysed by chemical means. It is recognized, however, that if such standards are available, spectrographic methods may prove a very convenient means of determining total boron in a sample, although they would not provide information as to the relative proportions of boron in the so-called 'soluble' and 'insoluble' forms, 'soluble' boron being the amount of boron in solution when the steel is dissolved in dilute acid. Since the state in which the boron is present is obviously of metallurgical significance, some investigation into the relative amounts of 'soluble' and 'insoluble' boron obtained by different solution conditions has been made.

Although a preliminary examination of the quinalizarin procedure was made, there seemed to be little hope of a direct method within the terms of reference, and the problem could therefore be divided into two parts, namely the determination and the separation of boron.

For the separation of boron, attention has been concentrated on (*a*) distillation as methyl borate[2] and

* The constitution of the Physico-chemical Methods of Analysis Sub-committee during the period of the boron investigation was: Mr. L. E. Gardner (*Chairman*, joined 1951), Edgar Allen & Co. Ltd.; Mr. B. Bagshawe (retired 1951), Brown-Firth Research Laboratories; Mr. D. Bell (retired 1953), Colvilles Ltd.; Mr. J. Booth (joined 1953, retired 1956), Park Gate Iron & Steel Co. Ltd.; Mr. H. Cox, Metropolitan-Vickers Electrical Co. Ltd.; Mr. H. C. Davies (retired 1951), Royal Aircraft Establishment; Mr. E. Dyke (joined 1951), Brown-Firth Research Laboratories; Mr. F. E. Eborall (retired 1953), George Senior & Sons Ltd.; Mr. C. H. R. Gentry, Philips Electrical Ltd.; Mrs. L. E. Greenfield, G.K.N. Group Research Laboratories; Mr. H. Groom, Bragg Laboratory, N.O.I.D.; Mr. S. Harrison, Kayser Ellison & Co. Ltd.; Dr. T. S. Harrison (joined 1952), Appleby-Frodingham Steel Co.; Mr. L. Kidman (joined 1956), English Steel Corporation, Ltd.; Mr. G. Padget, United Steel Companies Ltd.; Miss R. Presser (retired 1952), British Cast Iron Research Association; Mr. D. F. Sermin (joined 1953), Samuel Osborn & Co. Ltd.; Mr. H. G. Short (*Chairman* until March 1956), National Physical Laboratory. Acknowledgment is also made to Mr. D. R. C. Curry (Bragg Laboratory) and Mr. P. H. Scholes (B.I.S.R.A.) for work on behalf of the Sub-committee.

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Table I

COMPARISON OF THE SENSITIVITY OF BORON REAGENTS

Reagent	Optical Density (Ilford Filter of optimum wavelength) 10 μg B/50 ml—1 cm layer
Curcumin	0·25
Dianthrimide	0·2
Quinalizarin	0·03

(*b*) removal of metals by ion-exchange resins, leaving boron in solution. The final determination of boron has been carried out absorptiometrically, using curcumin or dianthrimide.

The main problem has been to devise a method of separation. For convenience, however, the absorptiometric determination will be dealt with first since the type of separation used has been to some extent conditioned by the details and sensitivity of the final procedure.

ABSORPTIOMETRIC DETERMINATION OF BORON

Quinalizarin Method

This is almost certainly the method most widely used by steelworks chemists.[1, 3, 4] The sample is dissolved in 20% v/v H_2SO_4 and an aliquot of the resulting solution is added to a larger volume of concentrated H_2SO_4 so that the final solution is equivalent to 92·5% v/v H_2SO_4. To the resulting solution, a small amount of quinalizarin solution is added, and after allowing the precipitated ferrous salts to settle, the blue colour produced by boron is compared with a set of standards containing known additions of boron.

The reagent itself in sulphuric acid is highly coloured and the colour varies with the amount of water present, from violet in strong acid solution to pink in solutions containing less than 90% H_2SO_4. Absorption curves of the reagent alone and of the boron complex are very similar, the reagent having an absorption maximum at 5300–5700 Å and the boron complex at 6000 Å. The reaction is therefore not particularly suitable for measuring with simpler spectrophotometers of the filter type.

The reaction was examined at several different acidities. Between 92·5% v/v and 97% v/v H_2SO_4, 0·5 μg increments of boron could be distinguished up to about 10μg total, corresponding to 0·005% of boron, and thence 1 μg increments up to 15 μg. Above 97% v/v H_2SO_4, the increasing blueness of the reagent solution made the detection of even 1 μg increments of boron very doubtful, and below 90% acid the reaction was much slower and less sensitive.

In a variation of the method examined by the Sub-committee, the actual colour test was carried out on 0·2 g of sample. By an experienced analyst an accuracy of ± 0·0005% boron can probably be attained. A disadvantage is that relatively small amounts of alloying elements, particularly chromium, interfere. Chromium up to 1% is the most that can be tolerated.

Curcumin Method

A number of methods for boron based on the reaction with curcumin have been proposed.[5] Boron, usually in the form of borate, after separation by distillation with methyl alcohol, is evaporated to dryness in an acid solution containing curcumin and oxalic acid. A red complex is formed and this can be extracted in alcohol and the intensity of the red colour measured. The test is approximately eight times as sensitive as quinalizarin with respect to the optical density produced by a given amount of boron. There are, however, considerable difficulties in its application.

The colour produced was found to be critically dependent on minor experimental details, e.g. the shape of the dish used for evaporation of the solution with curcumin and even the position of the dish on the water-bath. The intensity was also markedly decreased by quite minor amounts of sodium salts, e.g. whereas 10 μg boron gave an absorptiometer drum difference of 0·49, this was decreased to 0·32 by salts resulting from the presence of 1 ml 0·1-N HCl, and to 0·20 by 1 ml N-HCl.

Of the methods of separation under investigation, only distillation as methyl borate offered the possibility of obtaining the boron in a solution free not only from metals but also from neutral salts, and curcumin was therefore abandoned in favour of the following reagent which seemed to be less sensitive to minor variations in experimental conditions.

Dianthrimide Method

A number of anthraquinone derivatives, e.g. quinalizarin, give colours on heating with boric acid in sulphuric acid solutions, and dianthrimide[6, 7] is chemically in the same class, the colour being produced by the formation of a co-ordinate ring through nitrogen of the NH group instead of through oxygen of an OH group.

As with quinalizarin, the reaction must be carried out in concentrated sulphuric acid solutions; owing to its slowness this is generally done at elevated temperature.

A close approach to maximum colour development is obtained by heating for 5 h at 90° C and although at 105° C this time of heating may be reduced to 1½ h, the process cannot be continued indefinitely, because at higher temperatures the reagent itself begins to produce brownish colours with sulphuric acid. The boron–dianthrimide complex has a pronounced absorption peak with a maximum at 6400 Å, and a filter with maximum transmission at this wavelength is therefore desirable. Of the normal Ilford range of filters either No. 607 or No. 608 can be used.

Early trials were carried out at temperatures and times ranging from 95–105° C and 1½–5 h respectively, and considerable divergences of opinion on the reproducibility of the results were reported by different laboratories. Much of this early trouble was traced to uneven temperature distribution in the ovens used for heating the tests during colour development, 2–3° C difference between different zones of the oven being sufficient to cause measurable errors. As the reaction was speeded up by using higher temperatures, such differences became more important. In the

course of the investigation the tendency was therefore towards longer periods of heating at lower temperatures, and it was finally agreed that if a 4–5 h heating period was necessary, overnight heating in an oven would be no disadvantage. Conditions were therefore finally standardized at 16 h heating at 95° C. It must be emphasized that a well-lagged oven, giving the greatest possible uniformity of temperatures and preferably with a circulating fan, should be used.

In order to avoid loss of boron by volatilization during the long heating period, tests were carried out in stoppered bottles, which were nearly filled with solution, brought as rapidly as possible to 95° C, then lightly stoppered before being placed in the oven. Loss by volatilization does otherwise occur and it has been shown that lower values are obtained from tests in open vessels.

In Table I curcumin, dianthrimide, and quinalizarin are compared and it will be seen that the first two show a distinct advantage in sensitivity.

The boron–dianthrimide reaction is interfered with by traces of oxidizing agents, such as nitric acid, but not by ferrous iron nor by any of the elements usually present in steels, with the exception of pentavalent vanadium which presumably interferes through its oxidizing action.

The main disadvantage in the use of dianthrimide is the necessity to carry out the reaction in sulphuric acid of controlled concentration which must be at least 93% v/v. Since for reasonable sensitivity in the colour measurement, the volume of the solution should not be more than 50 ml, not more than 2·5 ml of sample solution can be taken for test, the balance being sulphuric acid (sp.gr. 1·84). After any separation the solution must therefore be concentrated to give the 3–4μg boron needed for a reasonable colour test within the 2·5 ml taken. This must be taken into account in the separation procedures used.

SEPARATION OF BORON FROM IRON AND INTERFERING ELEMENTS

Sodium Hydroxide Separation

Precipitation of ferric hydroxide by pouring the sample solution into sodium hydroxide solution was found to give reasonably satisfactory recovery of boron from the filtrate, but the method was abandoned for the following reasons:

(i) The alkaline solution could not be allowed in contact with any glassware: beakers of metal or special boron-free glass were necessary
(ii) On passing through filter papers, alkaline solutions removed some organic matter which interfered at the colouring stage by producing brownish colourations.

Mercury Cathode Electrolysis[8]

Loss of boron by evaporation of acid solutions to very low volume was easily demonstrated, and there was also a suspected loss of boron when alkaline solutions were evaporated to dryness. Some attention was therefore given to a method of separation which would give a solution of sufficiently small volume to enable an aliquot of 2·5 ml to be tested for boron without further concentration.

A 1-g sample was dissolved in 10 ml of 15% v/v H_2SO_4, oxidized with hydrogen peroxide, and electrolysed in a stirred mercury cathode cell. The volume

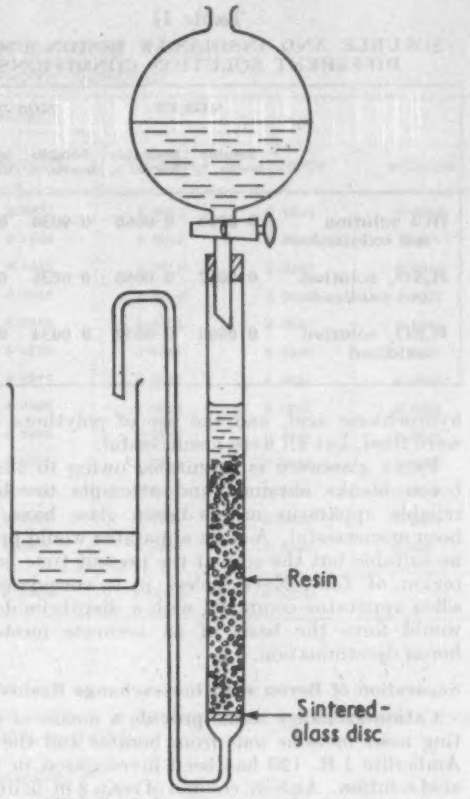

Fig. 1—Ion-exchange column

was diluted to 25 ml and a 2·5-ml aliquot taken for the reaction with dianthrimide.

Satisfactory recoveries of added boron were obtained by this method, the main disadvantage being the non-removal of vanadium, which subsequently interfered with the boron test by giving brown colours with the reagent. The additional steps necessary for the removal of vanadium then made the method cumbersome. Similar colours were also produced occasionally when vanadium was absent: this was thought to be due to soluble mercury salts present.

Distillation as Methyl Borate

The distillation procedure was known to have the advantage of complete separation of boron from all interfering elements, but the high cost of the apparatus and the difficulty in carrying out batch determinations were regarded as objections to its adoption as a recommended method. It was, however, decided to investigate the possible substitution of dianthrimide for the usual curcumin finish.

The distillation apparatus described in the 1950 A.S.T.M. Handbook for the Chemical Analysis of Metals (pp. 135–143) proved to be unsatisfactory. Traces of organic matter extracted from the rubber bungs passed into the distillate and, whilst insufficient to interfere with the curcumin test, charring followed heating with concentrated sulphuric acid. Various methods of overcoming this difficulty (previous extraction of the bungs, e.g. with concentrated

Table II

SOLUBLE AND INSOLUBLE BORON UNDER DIFFERENT SOLUTION CONDITIONS

	MGS/275		MGS/279	
	Soluble boron, %	Insoluble boron, %	Soluble boron, %	Insoluble boron, %
HCl solution not oxidized	0·0069	0·0060	0·0030	0·0010
H_2SO_4 solution not oxidized	0·0067	0·0058	0·0026	0·0011
H_2SO_4 solution oxidized	0·0069	0·0050	0·0034	0·0012

hydrochloric acid, and the use of polythene bungs) were tried, but all were unsuccessful.

Pyrex glassware is unsuitable owing to the high-boron blanks obtained and attempts to obtain a reliable apparatus in low-boron glass have so far been unsuccessful. A silica apparatus would probably be suitable but the cost at the present time is in the region of £50. Nevertheless it is considered that silica apparatus combined with a dianthrimide finish would form the basis of an accurate method for boron determination.

Separation of Boron with Ion-exchange Resins

Cation-exchange resins provide a means of separating most metallic ions from borates and the use of Amberlite I.R. 120 has been investigated in weakly acid solution. An 8-in. column of resin $\frac{5}{8}$ in. in diameter will deal with 1 g iron without allowing iron to pass into the eluate.

After passing through the resin column (Fig. 1) the volume of the solution is such that concentration is necessary. The solution is therefore made alkaline with sodium carbonate and evaporated to low volume in a boron-free beaker or a platinum dish. A 2·5-ml aliquot is then taken from a known small volume of solution (usually 5 ml) for the boron determination. It was shown that, by using an alkaline solution and avoiding the final evaporation to dryness, no loss of boron occurred.

It was expected that vanadium would pass through the resin column and cause interference, as in the mercury cathode separation. In practice, however, it was found that additions of pentavalent vanadium (equivalent to 1% in steel) to 0·5-g portions of boron-free iron gave no interference with the boron test, using either oxidizing or reducing conditions for solution of the sample. Nor could any vanadium be detected in the solution issuing from the column.

Certain precautions were found necessary for the satisfactory application of the resin columns. When a new column is put into service considerable washing with dilute acid is required to remove small amounts of organic matter which would later cause trouble by brownish discolourations at the colour development stage. Whether this is due to traces of soluble organic matter or to very fine resin particles was not established.

The column is regenerated by passing through it 20% v/v hydrochloric acid, followed by washing with water. After some time in use, it offers increased resistance to the flow of liquid, probably owing to the physical disintegration of resin particles; passing a current of water up the column from the bottom becomes necessary, the very fine particles being carried off at the top. After each such operation, a blank run should be made to check for organic matter passing into the eluate.

The colour obtained in a boron test on a boron-free solution which has passed through the resin column is always slightly higher than a direct blank on the reagents, and a 'column blank' should therefore be determined and applied in all boron determinations.

Table III

APPROXIMATE PERCENTAGE COMPOSITIONS OF SAMPLES

MGS Sample No.	Mn	Ni	Cr	Mo	Cu	V	Ti	Nb	W	Co
275	0·47	0·01	0·05	0·2	0·01	...	...	0·15	...	0·015
276	0·48	0·05	0·02	0·2	0·02	0·01	0·02	...	...	0·25
277	0·48	0·05	0·07	0·05	0·17	0·05	0·10	...	0·3	0·02
278	0·51	0·14	0·2	0·09	0·05	0·02	0·15	0·10	0·04	0·19
299	0·49	0·09	0·17	0·11	0·21	0·06	0·06	0·05	0·04	0·06
279	0·48	0·18	0·11	...	0·13	0·07	0·01	0·08	0·2	0·025
280	0·50	0·25	0·02	0·02	0·1	0·12	0·04	0·02	0·1	0·125

DETERMINATION OF SOLUBLE AND INSOLUBLE BORON

Solution of the sample can be carried out in dilute hydrochloric or sulphuric acid. Sulphuric acid is generally used, but in the case of samples high in chromium and low in boron, where interference due to chromium would be appreciable, hydrochloric acid is preferable.

In earlier boron methods, sulphuric acid solutions are oxidized by the addition of hydrogen peroxide, any insoluble matter is filtered off, and boron determined separately in solution and in the insoluble residue, giving the so-called 'soluble' and 'insoluble' boron contents. Some manufacturers use these figures as an empirical relationship, but the precise metallurgical significance of the distinction is not known, and there is no guarantee that all the boron reported as 'soluble' is in fact in solution in the sample. The samples examined have been dissolved in hydrochloric and sulphuric acids and in the latter both with and without oxidation. In general it appears that these modifications to solution conditions are not likely to affect the soluble and insoluble values. Typical determined values are given in Table II.

RESULTS ON SAMPLES

Much of the investigation has been carried out on the Mild Steel Residual Series of Spectrographic Standards, sponsored by the B.I.S.R.A. Spectrographic Analysis Sub-committee. The approximate compositions of the samples tested are given in Table III. Table IV gives the average results for the boron content of the samples obtained by members of the Sub-committee using the recommended method.

Table IV

DETERMINATION OF BORON IN MILD STEEL

Residual Series of Spectrographic Standards

Analyst	Boron, %						
	MGS/275	MGS/276	MGS/277	MGS/278	MGS/299	MGS/279	MGS/280
1	0·0139	0·0040	0·0020	0·0082	0·0011	0·0042	0·0010
2	0·0130	0·0036	0·0014	0·0086	0·0010	0·0043	n.d.*
3	0·0108	0·0030	0·0019	0·0082	0·0011	0·0040	< 0·0005
4	0·0155	0·0042	0·0026	0·0068	0·0024	0·0046	0·0007
5	0·0160	0·0034	0·0022	0·0085	0·0012	0·0042	< 0·0005
6	0·0115	0·0040	0·0028	0·0075	0·0015	0·0049	< 0·0005
7	0·0107	0·0039	0·0025	0·0074	0·0017	0·0046	0·0008
8	0·0141	0·0038	0·0023	0·0080	0·0012	0·0047	0·0008
9	0·0129	0·0033	0·0024	0·0090	0·0010	0·0040	0·0005
10	0·0140	0·0040	0·0026	0·0085	0·0016	0·0050	0·0003
11	0·0113$_5$	0·0038	0·0023	0·0081	0·0007	0·0041	< 0·0005
12	0·0112$_5$	0·0039	0·0021	0·0088	0·0008	0·0041	0·0006
Mean	0·0130	0·0037	0·0023	0·0081	0·0013	0·0044	< 0·001
Standard Deviation	0·00167	0·00034	0·00041	0·00064	0·00046	0·00033	...

* n.d. = not detected

CONCLUSIONS

A method has been developed for the determination of boron in the range up to 0·01%. This method has been satisfactorily applied to a series of mild steels and the results provide adequate evidence of good reproducibility in different laboratories.

A further programme of work is being carried out by members of the Sub-committee to extend the application of the method to boron-containing alloyed steels. This work will be reported in due course.

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APPENDIX

Recommended Method for the Determination of Boron in Steel

Principle

A solution of the sample in sulphuric or hydrochloric acid is passed through an ion-exchange column to remove interfering elements. The colour of the dianthrimide complex of boron is then developed in concentrated sulphuric acid.

Range

The method is applicable to boron contents from 0·0005% to 0·02%.

Application

The method is applicable to mild and low-alloy steels (less than 2% Cr, less than 5% V).

Reproducibility

In the range up to 0·005% B, replicate determinations should not differ by more than 0·0005%.

Apparatus

Glassware—Grade A glassware shall be used. Pipettes complying with B.S. 700 and graduated flasks complying with B.S. 1792 are suitable. Wherever possible, reactions shall be carried out in boron-free glassware.

Reaction Flask—A 150-ml boron-free flask fitted with a ground-glass joint and condenser.

Resin Column—The recommended ion-exchange resin column is shown in Fig. 1, and may conveniently be made of glass, about 10 in. long × $\frac{5}{8}$ in. internal diameter, closed at the bottom with a sintered-glass plate, and provided with the exit tube (6 mm dia.) bent at the bottom into an elongated **S**, so that the eluate emerges from a point above the level of the resin bed.

The column is filled with water and sufficient resin in the form of a slurry added to give a column 6 in. deep after settling. Any very fine material is previously removed by washing by decantation. After washing very thoroughly with water, the resin is converted to the hydrogen form by passing 200 ml HCl (20% v/v) through the column at a rate of approximately 3 ml/min, followed by 250–300 ml water to wash out the acid. The column may be regenerated by passing acid and water through it as above.

Air Oven—A well-lagged oven giving the greatest possible uniformity of heating, and preferably fitted with a circulating fan, should be used.

Photoelectric Absorptiometer—The colour is produced by the reagent with boron as an absorption band with a maximum at 6400 Å. The absorptiometer used may be of the balanced two-cell type (selenium photocells), in which case suitable conditions are: mercury vapour lamp, Ilford No. 607 and Calorex No. 503 heat-resisting filters, cell size 4 cm, range 0–10 μg boron. Other instruments of equivalent performance may be used, for which modifications in operational details will be necessary.

Reagents Required

All reagents shall be of the highest purity obtainable and boron-free distilled water shall be used throughout.

Resin for Column—A sulphonated cross-linked polystyrene resin, 16–52 mesh, as used for cation exchange, has been found suitable.

Sulphuric Acid (sp.gr. 1·84)—Unless otherwise stated, fresh concentrated 'Analar' sulphuric acid shall be used throughout. A stock of acid should be kept solely for this procedure.

Sulphuric Acid (7·5% v/v)—Cautiously add 75 ml of sulphuric acid (sp.gr. 1·84) to 900 ml of water whilst stirring. Cool and dilute to 1 litre.

Sulphuric Acid (50% v/v)—Continuously add 500 ml of sulphuric acid (sp. gr. 1·84) to 400 ml of water whilst stirring. Cool and dilute to 1 litre.

Dianthrimide Solution (0·02% w/v)—Dissolve 0·4 g of 1 : 1 dianthrimide in 100 ml of sulphuric acid (sp.gr. 1·84). Transfer to a lightly stoppered 4-oz bottle and store in a desiccator. When required, transfer 5·0 ml of this solution into a dry 100-ml graduated flask and dilute to the mark with sulphuric acid (sp.gr. 1·84).

Hydrochloric Acid (20% v/v)—Dilute 200 ml of hydrochloric acid (sp.gr. 1·16–1·18) to 1 litre.

Sulphurous Acid—Saturate 100 ml of water with sulphur dioxide.

Sampling

Recommended methods for obtaining a representative sample are described in British Standard 1837: Part 1.

Procedure

Transfer 0·5 g of sample to the small reaction flask. Add 10 ml of 7·5% v/v sulphuric acid (Note 1) and insert the reflux condenser (Note 2). Heat the flask gently. When solution appears to be complete, remove the condenser, cool and filter the solution through an acid-washed Whatman filter paper (Note 3), washing the residue with water. Reserve the insoluble residue for further treatment. Dilute the filtrate to 50 ml in a graduated flask.

Transfer 20 ml of the solution (Note 4) on to the top of an ion-exchange column prepared as described above and collect the eluate in a 250-ml boron-free beaker. Allow the solution and the first 10 ml of wash water to pass through the column at 1–2 ml/min. Wash the column with a further 140 ml of water at the rate of 3 ml/min. Neutralize the eluate with solid sodium carbonate using litmus paper as indicator (Note 5). Evaporate to about 20 ml and transfer to a 50-ml boron-free squat beaker or platinum dish. Continue the evaporation until the volume is less than 5 ml. Dilute the solution to 5 ml in a wide-necked graduated flask. Transfer 2·5 ml into a dry 50-ml boron-free beaker and add 10 ml of sulphuric acid (sp.gr. 1·84). Cool and transfer to a 50-ml graduated flask rinsing the beaker with sulphuric acid (sp. gr. 1·84), add 5·0 ml of dianthrimide solution (0·02% w/v), and dilute to 50 ml with sulphuric acid (sp.gr. 1·84). Mix well and transfer the solution to a narrow-necked glass bottle (capacity 30–40 ml) fitted with a stopper. Fit the stopper loosely and transfer to a well-lagged oven controlled at 95 ± 1° C. Heat for about 16 hours. Remove the bottle from the oven and allow to cool at room temperature. A blank should be carried through the column on corresponding quantities of all reagents used.

Measure the optical density on an absorptiometer with Ilford 607 filters using 4-cm cells. Obtain the difference reading between the absorption of the test solution and the reagent blank solution and hence determine the boron content of the sample by reference to a calibration graph prepared under identical conditions.

Insoluble Boron—For the determination of insoluble boron, weigh 0·5 g anhydrous sodium carbonate and sprinkle a little over the insoluble residue on the filter paper. Ignite in platinum at the lowest possible temperature, then add the remainder of the sodium carbonate and finally fuse at 1000° C. Cool and leach out with 3 ml of water and 1 ml sulphuric acid (50% v/v). If necessary, filter through a washed filter paper (Note 6) and determine boron on an aliquot of the filtrate as above (Note 7). Carry out a blank on the sodium carbonate and subsequent treatment.

Calibration

Dissolve 0·228 g boric acid (H_3BO_3) in water and dilute to 1 litre in a graduated flask. This solution contains 40μg boron/ml. Transfer 10 ml by means of a pipette into a 100-ml graduated flask and dilute to the mark with water. This solution contains 4μg boron/ml.

Using a 5-ml burette, run into a series of small beakers 0, 0·5, 1·0, 1·5, 2·0, and 2·5 ml of the diluted boron solution, representing 0, 2, 4, 6, 8, and 10μg boron. From another 5-ml burette, add water to the above series to bring the total volume of liquid to 2·5 ml in each case. Add 10 ml sulphuric acid (sp.gr. 1·84) and cool. Transfer to a 50-ml graduated flask, rinsing the beaker several times with sulphuric acid (sp.gr. 1·84), add 5 ml dianthrimide solution (0·02% w/v) and dilute to 50 ml with sulphuric acid (sp.gr. 1·84). Mix well and carry out the colour development and measurement as in the Procedure.

Prepare a calibration graph by plotting absorptiometer reading against micrograms of boron.

Notes

1. For chromium steels it is preferable to use hydrochloric acid (2·2 ml concentrated acid + 8 ml water) for solution of the sample. In sulphuric acid solution some chromium passes the resin column and gives a colour, which would be measured as boron. In hydrochloric acid solution the amount of chromium passing the column is very small (18% Cr ≡ 0·0004% B).

2. This apparatus should not be constructed of high-boron glass.

3. It must be emphasized that even good-quality filter papers contain small amounts of soluble boron and before use each paper should be washed with a solution of acid or alkali of approximately the strength of the test solution to be filtered and then with water.

4. The quantity of dianthrimide is only sufficient for 10μg boron, so that the aliquot must be reduced proportionately for concentrations greater than 0·01% boron.

5. With practice this point can be judged accurately, from the evolution of carbon dioxide without the use of an indicator.

6. If the solution is yellow at this point, add 1–2 ml saturated sulphurous acid solution and warm until the yellow colour has changed to green.

7. The volume of aqueous solution taken should not exceed 1·5 ml. If less is taken the volume of water present should be made up to a total of 2·5 ml.

Programme-controlled Reduction Test for Blast-furnace Burdens

By Rolf Linder

SYNOPSIS

The literature on the reducibility of iron ores is generally referred to ideal conditions which do not resemble those actually met in the blast-furnace. To arrive at an exact value for the reducibility of an ore, the classical methods of testing should be replaced by others where the conditions approach more closely to those in the blast-furnace; the temperature and reducing action of the gas should increase with reduction time as well as the mechanical stressing of the ore.

The paper seeks to establish a relation between the behaviour of the ore in a certain laboratory test and in the blast-furnace. The quality of the ore is characterized by four factors: composition, mechanical strength, reducibility, and resistance to breakup during reduction. As a criterion of reducibility the degree of oxidation of the ore when heated to 1000° C in a reducing atmosphere is measured. The correlation between the test value and the actual degree of oxidation as direct reduction begins in a blast-furnace is discussed, and equations are given for calculation from blast-furnace data of the distribution between indirect and direct reduction. The paper describes the apparatus and method of use. It consists mainly of an electrically heated rotating cell and apparatus for gas generation and analysis. The rotation of the cell is intended to assist mechanically in the reduction of the ore. The temperature and gas composition vary during the test according to a predetermined scheme. The test finishes when the temperature reaches 1000° C.

To estimate the breakup of the ore during reduction, the amount of fines produced is determined. For Oxelösund and Domnarfvet sinters the tests have shown very good agreement between the reducibility determined in this way and blast-furnace indirect reduction. 1544

NEED FOR REDUCTION TEST RELATED TO PRACTICAL BLAST-FURNACE OPERATION

THE LITERATURE dealing with reduction experiments on iron ores is predominantly concerned with investigations of the fundamental chemical and thermal processes under idealized conditions. They usually consist of studies of the reduction processes on stationary specimens in an atmosphere of pure hydrogen or carbon monoxide at a constant reduction temperature.

Many objections can be raised to this method of evaluating the reducibility of iron ores for blast-furnace burdens. The conditions to which the ore is subjected in the blast-furnace imply a successive, though not uniform, heating in an atmosphere whose reducing capacity is increasing continuously. The ore is simultaneously exposed to powerful mechanical stresses in the form of abrasion under increasing pressure of the material. It is also generally recognized that in the blast-furnace stack the iron compounds in the ore pass through a number of consecutive and partially superimposed processes of reduction, in stages leading to a state of steadily lower oxygen content. These reactions are summarized in Table I, which also gives their probable initial and final temperatures in the blast-furnace stack.

Iron hydroxides and carbonates are decomposed in the upper part of the stack, the unstable wüstite being converted into magnetite under the influence of an atmosphere which oxidizes iron. This magnetite, together with that formed from hematite, can be reduced to iron at temperatures below 570° C. A partial reduction such as this undoubtedly takes place and the iron formed acts as a catalyst for the decomposition of the carbon monoxide; carbon is deposited in the ore as a result. The iron is probably oxidized simultaneously, so that wüstite or magnetite is again formed. The strongly reactive precipitated carbon again reacts at temperatures above 700° C

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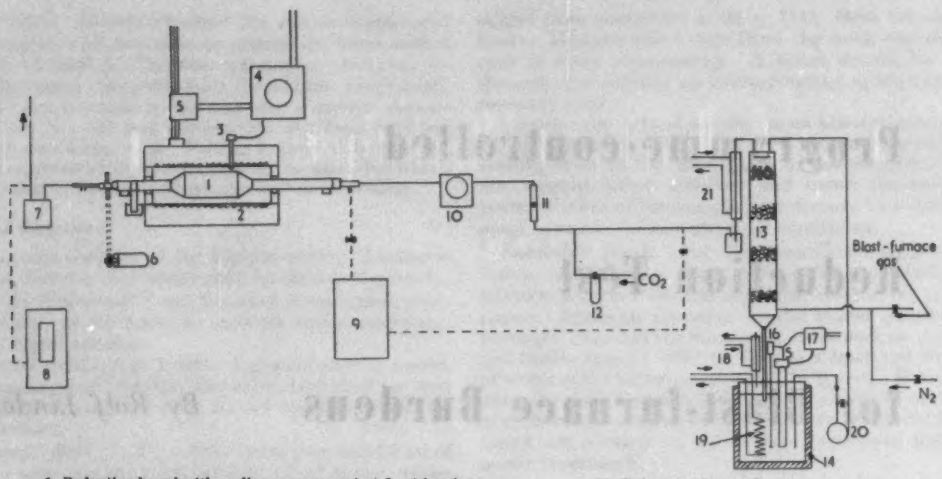
Mr. Linder is with Oxelösunds Järnverks AB, Sweden.



1. Reduction barrel with cooling arrangement at front bearing
2. Furnace, 3-phase, 15 kW for max. 1100° C
3. Thermocouple with protecting tube and compensation cable
4. Regulator for temperature programme
5. 0–220–380 V relay
6. Repulsion motor with worm gear and chain drive
7. Dust collector
8. Automatic gas analysis apparatus
9. Orsat apparatus for gas composition control
10. Gasometer for gas volume
11. Rotameter for gas flow
12. Capillary flow meter for CO_2 addition
13. Washing tower
14. Insulated container for washing solution
15. Immersion heater
16. Contact thermometer
17. On–off relay
18. Reflux cooler
19. Cooling coil
20. Pump
21. Gas cooler with draining receptacle

Fig. 1—Principal diagram of reduction-test apparatus and gas-washing equipment

and is considered to facilitate the reduction of the magnetite to wüstite, and the reduction of wüstite to iron. Carbon precipitation is believed to have a fracturing and disintegrating effect on the iron ore, which presumably facilitates the continued reduction by gas. At about 900° C, the coke carbon is so highly reactive towards CO_2 that part of the carbon dioxide resulting from the gas reduction again forms CO, with consumption of carbon. This process, which implies direct reduction of solid iron oxides, is most likely dominant at 1100° C; 1000° C can be assumed to be an average temperature for the initiation of direct reduction with coke carbon, if dense metallurgical coke, low in ash content and with a high strength index, is used. The complete reaction when wüstite is regarded will be

$$FeO_s + C_{coke} = Fe + CO$$

and, as melts are probably formed at about 1120° C in the presence of CaO and SiO_2, true direct reduction

$$(FeO)_{liq.} + C_{coke} = Fe + CO$$

also begins and leads to the final reduction of the iron oxides.

This condensed description of the reduction processes in a blast-furnace should justify the claim that reduction tests at constant temperature and gas composition can be of little value for classifying ores according to reducibility. In order to arrive at a correct evaluation of ores on a laboratory scale, it is obviously necessary to adopt a method which approximates to the conditions in a blast-furnace. Reduction must take place under rising temperature and the composition of the reducing gas must be changed so as to resemble the increasingly reducing gas the ore will meet as it passes down the blast-furnace stack. The ore sample must also be subjected to mechanical stress in the course of the experiment, so that the weakening of the ore which generally occurs during reduction will result in corresponding disintegration. Finally, the method should be such that the sample can be large enough to counterbalance any chance variations in the properties of the individual ore lumps.

The idea of a programme-controlled reduction experiment such as this is not entirely new. In 1951, Schenk[1] described experiments on these lines carried out at the Aachen School of Mines and Klementaski[2] recently briefly described a similar experimental procedure being planned by B.I.S.R.A. McLeod[3] has described reduction experiments in

Table I
CHEMICAL PROCESSES IN GRADUAL REDUCTION OF IRON COMPOUNDS IN THE BLAST-FURNACE STACK

Reaction	Probable Temperature Range for Main Part of Reaction, °C
$Fe(OH)_3 \rightarrow Fe_3O_4$	25–350
$FeCO_3 \rightarrow Fe_3O_4$ $Fe_2O_3 \rightarrow Fe_3O_4$ $Fe_3O_4 \rightarrow Fe$ $2CO = C_{precip.} + CO_2$ $Fe \rightarrow Fe_3O_4$ (or FeO)	350–700
$Fe_3O_4 \rightarrow FeO_s$ Part of $FeO_s \rightarrow Fe$ $C_{precip.} + CO_2 = 2CO$	700–1000
$FeO_s \rightarrow Fe$ $C_{coke} + CO_2 = 2CO$ $FeO_{liq.} + C_{coke} \rightarrow Fe$	1000–1200

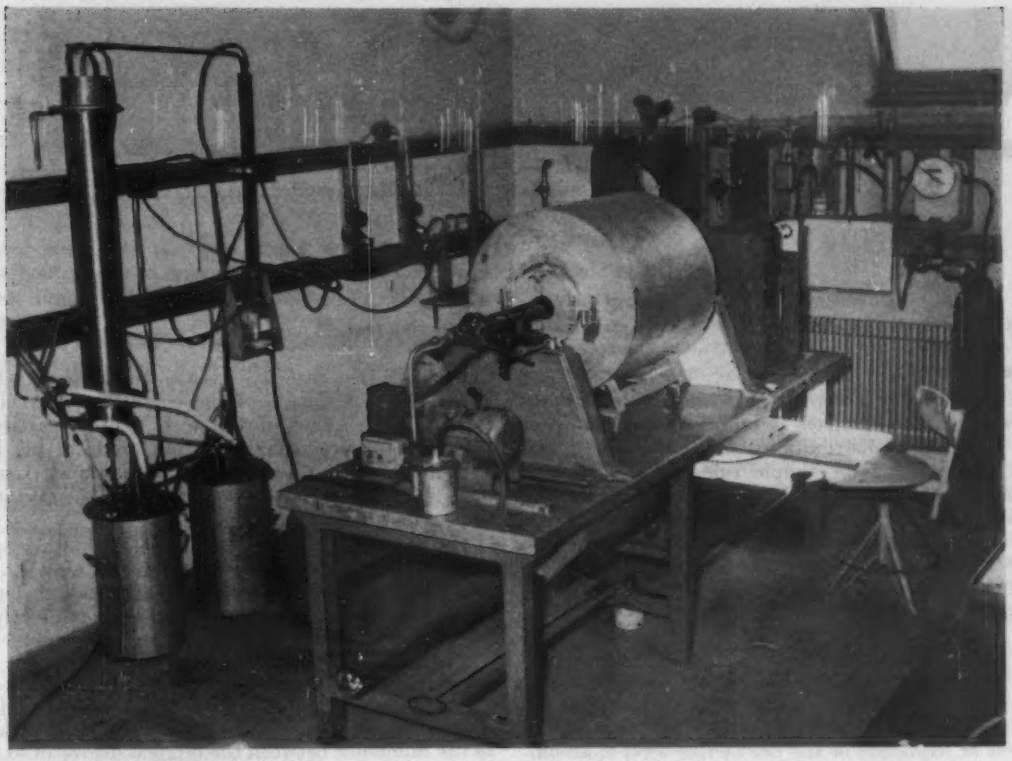


Fig. 2—Laboratory plant for programme-controlled reduction tests

Table II

CALCULATION OF DISTRIBUTION BETWEEN INDIRECT AND DIRECT REDUCTION IN BLAST-FURNACE OPERATION

At Oxelösund and Domnarvet

	Oxelösund: Open-hearth Pig-Iron	Domnarfvet: Basic Bessemer Iron
Fe reduced, kg/ton of pig iron	932	936
$V_{theor.}$, std.m³	560	564
Blast-furnace gas volume, std.m³	3000	1960
Volume of CO_2 in blast-furnace gas, std.m³	303	343
Volume of CO_2 from limestone, std.m³	56	0
Volume of CO_2 from indirect reduction, std.m³	247	343
Volume of H_2O from indirect reduction,* std.m³	− 12	28
V_{actual}, std.m³	235	371
$100 \cdot V_{actual}/V_{theor.}$	42	66
Original degree of oxidation of sinter, %	96	98
Degree of oxidation at initiation of direct reduction ($Deg.oxd._{1000°C}^{bl.\ furn.}$)%	54	32

* A negative value indicates that water-gas reaction occurred to such an extent that the volume of hydrogen in the blast-furnace gas exceeds the quantity of hydrogen introduced with blast humidity and hydrocarbons in coke.

blast-furnace gas rising linearly in temperature. None of these methods, however, fulfils all the conditions indicated above. The method to be described in the present paper is an adaptation to the blast-furnace process of a procedure originally developed by Stålhed[4] at the Söderfors sponge-iron plant for investigating the strength of ore during reduction.

CRITERIA FOR REDUCIBILITY AND STRENGTH OF ORE DURING REDUCTION

The suitability of an ore for blast-furnace use is chiefly determined by four factors:

1. Composition
2. Handling strength
3. Reducibility
4. Strength in reduction.

The importance of the first two has been dealt with in many publications, and their influence on the suitability of an ore for blast-furnace burden can, on the whole, be said to have been established. Reducibility has, as already mentioned, attracted a great deal of attention, but it has usually been studied by methods not entirely suitable for direct application to the blast-furnace process. The strength in reduction of the ore has, however, received almost no attention in connection with blast-furnace operation. The concept of reduction strength was first considered in Sweden in connection with the Wiberg sponge-iron process, in which a shaft furnace is charged with iron ore alone without any admixture of coke. A systematic study of this property was carried out on the first plant of this type by Stålhed.[4]

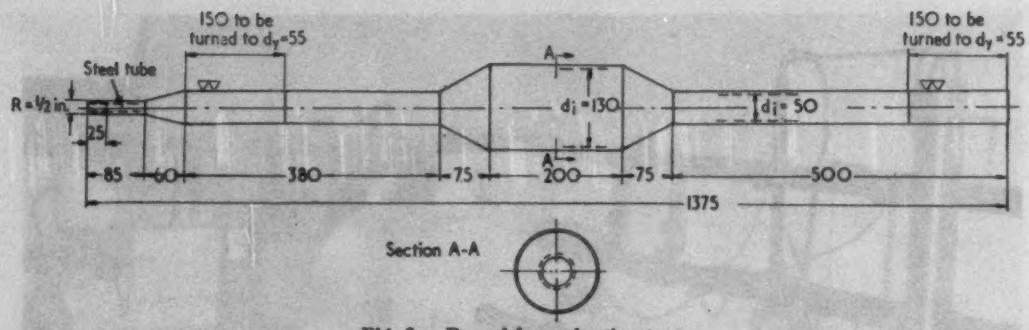


Fig. 3a—Barrel for reduction test

Reducibility of Iron Ores

It is generally accepted that the reducibility of an ore in a blast-furnace is represented by more or less favourable distribution between indirect and direct reduction.* A simple rule applies here: all reduction which does not take place indirectly will be accomplished directly, with consumption of carbon and with a resulting increase in the heat required. Direct reduction of wüstite is described by the reaction:

$$FeO + C = Fe + CO \qquad \Delta H_{1400^\circ K} = 35{\cdot}9 \text{ kcal/mol} = 3{\cdot}0 \text{ Mcal per kg of carbon}$$

and this implies that if 2Mcal per kg of carbon burnt in front of the tuyeres can be utilized to supply the heat needed above 1000° C, a 10% increase in the degree of oxidation of the ore at this level is accompanied by an increase in the rate of carbon consumption of about 75 kg per ton of pig iron, of which 30 kg are consumed chemically and 45 kg are needed to increase the output of heat. This corresponds to about 90 kg of coke as used in the blast-furnace operation, in which the critical temperature is 1000° C or lower. Satisfactory indirect reduction is therefore essential for a low coke rate; the degree of oxidation of the ore at the 1000° C level (' Deg. oxd. $_{1000^\circ C}$ ') is used here as a measure of its reducibility. In blast-furnace operation the numerical value of this concept naturally also depends on the time intervals between the different temperature levels in the stack, and on the composition of the stack gas (e.g. in so far as hydrogen content, CO/CO_2 ratio, gas distribution, and other operating conditions are concerned), but in a programme-controlled reduction experiment under standardized conditions it can be regarded as a purely material function. Deg. oxd. $_{1000^\circ C}$ can be calculated from operating data for a working blast-furnace, and it should therefore be possible, in the case of an unknown ore, to arrive at a satisfactory quantitative approximate value from the relationship

$$\text{Deg. oxd.}\,{}^{\text{bl. furn.}}_{1000^\circ C} = \text{Deg. oxg.}\,{}^{\text{test}}_{1000^\circ C} + \Delta\text{Deg. oxd.}_{1000^\circ C} \quad (1)$$

in which Δ Deg. oxd. $_{1000^\circ C}$ is a correction term which allows for a deviation of the conditions in a blast-furnace from those of the test. For a particular blast-furnace producing a certain grade of pig iron and working on a similar ore with known testing data this term could be calculated from the operating data using the same relationship.

Deg. oxd. $^{\text{bl. furn.}}_{1000^\circ C}$ can be connected with other operating data and calculated from the CO_2 and H_2 contents of the blast-furnace gas, if it is assumed that all reduction of iron oxide is carried out directly at temperatures above 1000° C. The equation

$$\text{Deg. oxd.}\,{}^{\text{bl. furn.}}_{1000^\circ C} = \text{Deg. oxd.}_{\text{orig.}} - \frac{V_{\text{actual}}}{V_{\text{theor.}}} \cdot 100 \quad \ldots(2)$$

states that the degree of oxidation can be calculated as the difference between the original degree of oxidation of the ore and the quotient between the actual and theoretical maximum volumes of carbon dioxide and water vapour formed in indirect reduction of the iron oxides. The theoretical volume obtained in entirely indirect reduction of iron ore with 100% hematite can be calculated at 602 std.m³ per ton of reduced iron from the formulæ:

$$Fe_2O_3 + 3CO = 2Fe + 3CO_2 \text{ and}$$
$$Fe_2O_3 + 3H_2 = 2Fe + 3H_2O,$$

whereas the actual volume of CO_2 and H_2O from indirect reduction is calculated from the volume of CO_2 in the blast-furnace gas, deducting the CO_2 derived from carbonates, and the difference between the sum total of hydrogen introduced as humidity in the blast and with hydrocarbons in coke, and the volume of hydrogen remaining in the blast-furnace gas. Two examples of these calculations are shown in Table II.

In calculating V_{actual} it is of no significance if the homogeneous water–gas reaction

$$CO + H_2O = CO_2 + H_2$$

occurs in the upper part of the shaft, as every increase in the volume of CO_2 corresponds to an equally large increase in the volume of hydrogen in the blast-furnace gas. If the heterogeneous water-gas reaction according to the formula:

$$C_{\text{precip.}} + H_2O = CO + H_2$$

takes place by reaction (e.g. between water of crystallization in the ore and precipitated carbon), this

* In this paper, direct reduction is defined as being the sum of the reduction by gas of solid iron oxides taking place at a temperature (above 1000° C) at which the carbon dioxide or water vapour formed reacts with coke carbon to form carbon monoxide and hydrogen again and of true direct reduction, which occurs when molten iron oxides come into contact with coke carbon.

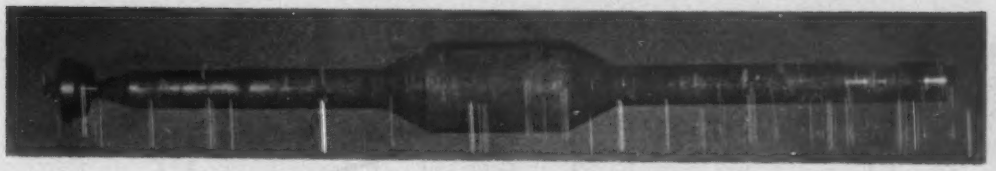


Fig. 3b—Photograph of barrel for reduction test

does not affect the final result, as the quantity of carbon consumed does not react with carbon dioxide, resulting in a higher CO_2 content in the blast-furnace gas.

These calculations assume that the dry volume of blast-furnace gas (M) is known. As this is not usually measured, it should be calculated from the blast volume (Bl). Equation (3) indicates how this is arrived at by using the content of nitrogen in the dry blast-furnace gas. The blast humidity content should be known when a very accurate calculation is made, but the relation can be modified in practical calculations to equation (3a):

$$M = Bl \cdot \left(1 - \frac{\%H_2O_{Bl}}{100}\right) \cdot \frac{79 \cdot 07}{\%N_{2M}} \quad \ldots\ldots\ldots\ldots(3)$$

is simplified to

$$M = Bl \times 1 \cdot 32 \quad \ldots\ldots\ldots\ldots(3a)$$

$$\text{at } \%H_2O_{Bl} = 1 \cdot 0 \text{ and } \%N_{2M} = 59 \cdot 5$$

Occasionally the blast volume is not measured or the determination is uncertain. In such cases the blast volume should be calculated from the carbon balance. This is indicated by:

$$C_{charged} - C_{flue\ dust} = C_{dir.red.Fe} + C_{dir.\ red.\ alloys} + C_{pig\ iron} + C_{burnt} \quad \ldots\ldots\ldots\ldots(4)$$

in which the symbols are in kg of carbon per metric ton of pig iron. The carbon consumption for direct reduction of iron oxides can be calculated, according to the reduction formula

$$Fe_2O_3 + 3C = 2\,Fe + 3CO$$

as

$$C_{dir.\ red.\ Fe} = 0 \cdot 322 \frac{\text{Deg. oxd.}\ ^{\text{bl.furn.}}_{1000^\circ C}}{100} \cdot Fe_{red.} \quad \ldots\ldots(5)$$

in which $Fe_{red.}$ is the reduced quantity of iron in kg per metric ton of pig iron, i.e. the difference between the quantity of iron in the pig iron and in the scrap charged.

Carbon burnt with air can be calculated from the equation:

$$C_{burnt} = 0 \cdot 224 \,.\, Bl \quad \ldots\ldots\ldots\ldots(6)$$

in which Bl is the volume in std. m³ of air blown per ton of pig iron, whereas the carbon rate for reduction of the oxides of the alloy elements and carburization of the pig iron can be calculated from the composition of the pig iron and the respective reaction formula.

The blast volume (Bl), the blast-furnace gas volume (M), and the degree of oxidation of the ore at the 1000° C level (Deg. oxd. $^{\text{bl. furn.}}_{1000^\circ C}$) can therefore be calculated from the equations given when the composition of the burden, the blast-furnace gas, and the pig iron are known. It should be emphasized that in such a calculation only coincident average values for periods of satisfactory length (at least a week) should be used.

Disintegration of the Ore in Reduction

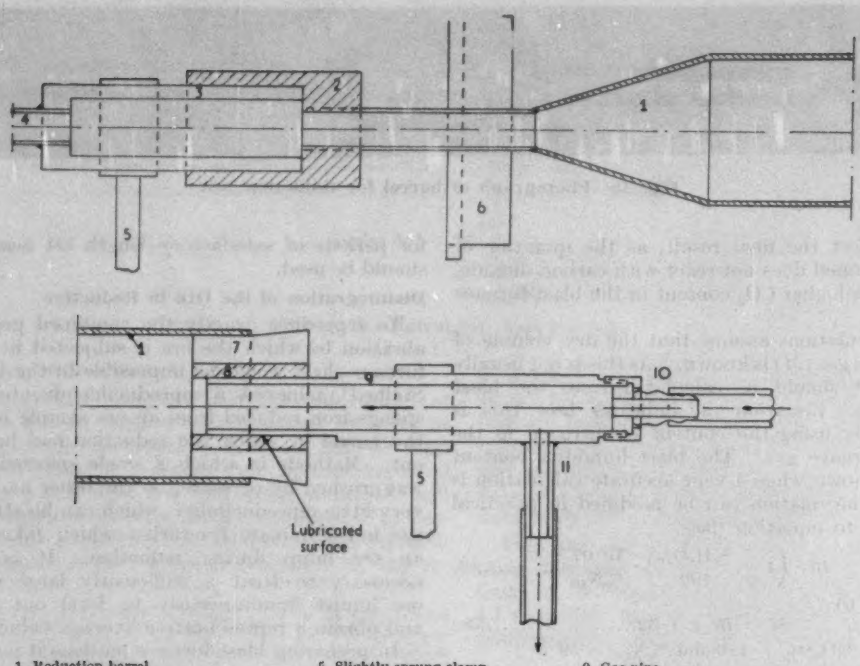
To reproduce exactly the combined pressure and abrasion to which the ore is subjected in the blast-furnace shaft would be impossible in the laboratory. Stålhed[4] achieved a reproducible disintegration of sponge iron reduced from an ore sample by rotating the barrel in which the reduction had been carried out. Methods in which a single selected ore lump was crushed by pressure, on the other hand, showed very little reproducibility, which can be attributed to the indiscriminate fracturing which takes place in an ore lump during reduction. It is therefore necessary to treat a sufficiently large number of ore lumps simultaneously to level out this effect and obtain a representative average value.

In preparing blast-furnace burdens it is considered advisable not to charge the blast-furnace with particles of less than 6 mm; these are removed by screening immediately before charging. So far as disintegration during reduction, which can be expected to take place some way down the shaft, is concerned, different conditions will apply, since the column of material above the level of disintegration can undoubtedly separate and retain particles of less than 6 mm from the gas flow. It is also known that particles coated with reduced iron are apt to stick together and form larger agglomerates. There are therefore good reasons for lowering the critical dimension limit to 3 mm and considering only fines below this size as contributing to an increase in the quantity of flue dust and to a greater drop in pressure within the column of material. On the other hand, special attention should be paid to the role of fines of less than 1 mm, formed during reduction, as this fraction, in addition to having a most adverse effect for the reasons mentioned, probably also contributes in a large measure to the formation of scaffolds.

If this line of thought is followed, the disintegration of ore in reduction is characterized by the two concepts ' coarse disintegration ' and ' fine disintegration', the former indicating material less than 3 mm and the latter that less than 1 mm produced in the reduction test. These quantities are expressed as percentages, either of the weight of the ore or of the weight of the iron in the ore. The first alternative expresses the property of the ore more accurately, but the latter provides a value proportional to the quantity of fines formed per ton of pig iron.

APPARATUS FOR REDUCTION AND PRODUCTION OF REDUCING GAS

The complete laboratory plant for carrying out a reduction test according to the principles outlined



1. Reduction barrel
2. Rotating-tube
3. Fixed tube
4. Copper tubing to dust collector
5. Slightly sprung clamp
6. Sprocket
7. Rubber plug
8. Brass bushing
9. Gas pipe
10. Connection for hose
11. Branching for gas-control analysis

Fig. 4—(*a*) Detail of barrel exhaust end; (*b*) detail of gas-inlet end

above comprises apparatus for the production of the necessary gas mixture, in addition to a barrel for reducing and abrading the ore sample and the furnace equipment required for heating. Where blast-furnace gas is available, the gas can be obtained by washing CO_2 out of it with a regenerative washing liquid (e.g. monoethanolamine). Figure 1 is a diagram of this type of laboratory plant, and Fig. 2 shows the plant used at Oxelösund, with furnace, programme temperature regulator, gear drive, and gas-washing apparatus, as well as gasometer and gas analytical apparatus for control of the volume and composition of the reduction gas.

Mechanical and Electrical Equipment

The most important part of the reducing apparatus is the barrel (*see* Figs. 3*a* and *b*) in which the reduction and abrading of the ore is carried out. This should be made of alloy-steel sheet with a scaling temperature of not less than 1025–1050° C. It is set up in bearing-halves at each end of an electric furnace with doors opening vertically. The barrel can be made to rotate by means of a chain drive connected to a sprocket mounted on the end of the gas outlet pipe.

During the test the reducing gas is led through the barrel, precautions being taken to avoid leakage at both ends. The prevention of leakage is difficult because the barrel increases in length and loses its straightness as a result of heating, but a satisfactory result has been achieved by the arrangement shown in Figs. 4*a* and *b*. It is essential that water-cooling of the barrel tube should be situated immediately inside the front bearing; this can be done by wrapping a cloth tape round the tube, and have it dipping in a water container and driven by the rotation of the barrel. The gas-inlet end can be constructed so as to absorb the expansion of the tube, while the gas outlet is designed so that dust carried by the gas will not contaminate the lubricated contact surface. This dust is separated from the gas by a dust collector, which is filled with glass wool (*see* Fig. 5).

The furnace is tubular (220 mm i.d., 600 mm long) and has direct-radiating heating elements which have been given an effect of 3 × 5 KW at 380 V. The desired range of temperature is obtained with the aid of a programme-temperature regulator which affects the voltage on the furnace in stages of 0–220–380 V via two relays. The thermocouple (Pt/Pt–10%Rh), sited 200 mm from one end, has its junction immediately inside the Kanthal protective tube without intermediate ceramic insulation. Lags are thus kept to a minimum in the rapid temperature changes which occur.

Supply of Reducing Gas

The reducing gas required can, of course, be produced by mixing the pure gases in desired proportions. At a gas velocity of 15 l./min, 4·5 m^3 of reducing gas are consumed in each test, however, and the cost of compressed carbon monoxide is high. Where blast-furnace gas is available the cheapest and simplest method would be to wash this with a regenerative washing liquid to remove the CO_2. The final CO_2 content in the gas mixture can be controlled by adding this to the washed gas from a gas container.

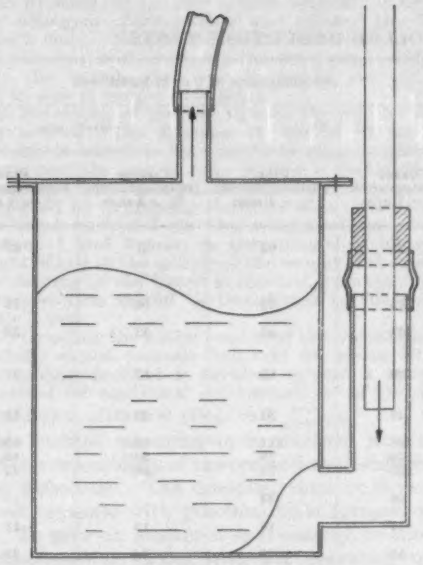


Fig. 5—Dust collector for laboratory reduction plant

An apparatus for this purpose, constructed in stainless steel and operating with a 50% solution of monoethanolamine in water, is shown in Fig. 1. From a vessel insulated with slag wool and equipped with an immersion heater, cooling coil, contact thermometer, and reflux cooler, the washing liquid is circulated by a gear pump via a gas-washing tower in which it meets the gas, and the absorption of CO_2 takes place. The washing liquid is theoretically able to dissolve about 115 l. of CO_2 per litre of solution but, as complete regeneration is difficult, a certain surplus must be taken into account. Experience at Oxelösund has shown that complete cleansing ($< 0{\cdot}1\%$ CO_2) of $4{\cdot}5$ m³ of blast-furnace gas from about 10% CO_2 (450 l. in all) can easily be achieved with a 20-l. solution. When the washing liquid has been used for one test it can be regenerated by boiling, the immersion heater fitted in the assembler being regulated by the contact thermometer via a relay. With a boiling temperature of 108° C and the introduction of an effect of 3 KW per 10 l. of solution, satisfactory regeneration is obtained in about 6 h. The outgoing mixture of water vapour and CO_2 is passed through a reflux cooler fitted in the lid of the vessel, the water vapour condensing and the water

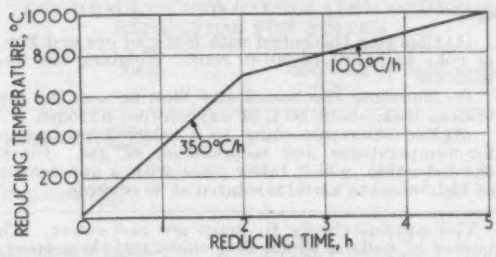


Fig. 6—Temperature programme selected for reduction test at Oxelösund

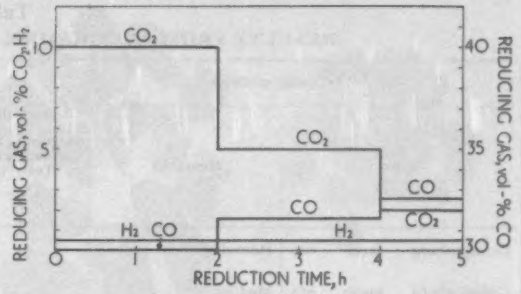


Fig. 7—Alteration by stages in composition of the reducing gas in tests at Oxelösund. Incoming blast-furnace gas contents 10% CO_2, 40% CO + CO_2, 0·5% H_2, 59·5% N_2

returning to the vessel. When the solution has been boiled it is again cooled to a working temperature (10–25° C) with the cooling coil. To reduce the temperature and humidity of the reducing gas it has been found convenient to fit a cooler immediately behind the washing tower with a draining vessel containing concentrated sulphuric acid.

The plant should further be equipped with a rotameter for controlling gas flow and a gasometer for summing up the gas volume passed. The comparatively small volumes of CO_2 added to the reducing gas after the washing tower are best measured with a capillary gas-flow meter. The composition of the reducing gas should be checked at regular intervals, and for this purpose a gas-analysis apparatus of the Orsat type is suitable. The complete tubing system with barrel and washing tower must be flushed with oxygen-free nitrogen before and after each test. This gas is produced from nitrogen of normal purity which, after a controlled addition of hydrogen, has been passed through a palladium catalyst and a drying tower.

The progress of the reduction during the test can be followed, if desired, with an accurate automatic gas-analysis apparatus for CO_2 (and possibly also H_2) determinations, connected after the dust collector, as shown in Fig. 1.

TEST METHOD AND EVALUATION OF RESULTS

With the apparatus described it is possible to carry out reduction tests in which the reduction temperature as well as the composition of the reducing gas are changed according to a desired programme. This should, of course, follow as closely as possible the actual thermal and chemical conditions which apply in the blast-furnace stack and which are largely determined by the distinctive character of the operation, when such factors as the grade of the pig iron manufactured, the coke rate, and the production rate used are particularly essential.

Temperature Programme

Measurements at different Swedish blast-furnaces,[5–7] where the iron-bearing part of the burden is sinter, have shown that the heating to about 700° C is rapid and that the rate of heating from then on will be essentially lower during a period which ends

Table III

RESULTS FROM PROGRAMME-CONTROLLED REDUCTION TESTS

Quality of Ore		Reducibility:	Disintegration of Ore in Reduction			
			wt-% Fe		wt-% ore	
Type	Remarks	Degree of Oxidation after Test, %	Coarse Disintegration, % < 3 mm	Fine Disintegration, % < 1 mm	Coarse Disintegration, % < 3 mm	Fine Disintegration, % < 1 mm
Grängesberg lump ore	Hematite	64	94	94	57	57
Grängesberg lump ore	Magnetite	76	26	25	16	15
Sinter from Domnarfvet	Self-fluxing	35	102	65	52	33
Sinter from Oxelösund	Not self-fluxing, blackburnt	54	100	65	57	37
Sinter from Oxelösund	Not self-fluxing, slagged	62	49	31	28	18
Sinter from a test strand	Top layer	54	145	111	83	63
	Centre layer	54	144	79	82	45
	Bottom layer	70	120	74	68	42
Pellets fired on a strand	10 mm dia.	60	60	34	...	...
Pellets fired in a shaft furnace	20 mm dia. dense	65	19	16	13	11
" " "	20 mm dia. porous	47	50	48	34	33

at about 1000° C. The temperature then rises more rapidly again above this limit. If the burden contains hydrates and carbonate (limestone) and the upper part of the stack becomes further thermally loaded, the rates of heating during both these periods are modified so as to be slower during the first period and more rapid during the latter. A high production rate with consequent short time of passage contributes generally to raise the rate of heating.

On the basis of these concepts and of measurements at the blast-furnace at Oxelösund, a temperature programme was chosen for the test consisting of two linear rises in which 700° C is reached in 2 h and 1000° C in another 3 h. The range, which is illustrated in Fig. 6, indicates a heating rate of 350° C/h during the first period and 100° C/h during the second. The entire time of reduction will be 5 h and therefore corresponds to the time which has elapsed between the charging of the ore in the stack and attainment of the 1000° C level.

Composition of the Reducing Gas

Owing to the variations in the stack gas in a blast-furnace, and arising out of the practical possibility of producing the reducing gas from blast-furnace gas, a schedule was adopted for the test at Oxelösund in which the composition of the reducing gas is altered in three stages. During the first 2 h the CO_2 content is kept at 10%, after which it is reduced to 5% for the next 2-h period. During the last hour, only 2% CO_2 is used. It would certainly be difficult and also pointless to alter the composition of the reducing gas continuously, as it is difficult to draw up a definite programme. The one chosen has been illustrated by Fig. 7. An investigation of the influence of the rate of gas flow showed that with 15 l./min and a test sample weighing 500 g a reduction effect was obtained which was not affected by a further increase in the quantity of gas.

Determination of the Disintegration of the Ore

To ascertain the effect of abrasion on the sample, the barrel must be rotated at a fairly high speed. The speed should be chosen so that distinct differences may be observable between materials of the types which may be tested. Experiments have shown that a speed of 30 rev/min throughout the entire period of reduction gives the desired result. It has been found to be a good idea to mix the ore sample with coke of the same size. The original size of the lumps of the ore sample and the coke should be fixed within rather narrow limits* and the disintegration be determined by screening the reduced and cooled sample with 1- and 3-mm screens after removing the coke by hand. Experience has shown that, with a sample of 500 g of ore and 200 g of coke in lumps of 30–40 mm, the coke loses 5–15 g from corners and edges being worn off; this quantity is found in the fraction below 1 mm. It is therefore advisable to subtract the loss in weight of the coke from the weight of the fines below 1 mm. This is determined by the sum of the fines passing through the 1-mm screen and the increase in weight of the dust collector.

Working Schedule and Treatment of Samples

A complete reduction test comprises the following stages:

(1) Charging the barrel with 500 g of ore and 200 g of coke in lumps of 30–40 mm. Weighing the dust collector

(2) Mounting the barrel and blowing out the pipe system with about 50 l. of oxygen-free nitrogen

(3) Reduction according to a selected programme for temperatures and composition of gas. During the reduction, which takes place with a gas velocity of 15 l./min, the barrel is rotated at 30 rev/min

* This applies chiefly to lump ore and sinter. The diameter of pellets, which is a characteristic property, should be maintained and stated when describing the sample.

(4) Blowing out the pipe system with 50 l. of oxygen-free nitrogen. Dismantling and closing the barrel at both ends. Weighing the dust collector

(5) Cooling and emptying the ore sample and coke from the barrel. The coke is picked out by hand and its loss in weight determined

(6) Screening of the ore sample through 3- and 1-mm screens. The increase in weight of the dust collector is added to the weight of fines smaller than 1 mm, and the loss in coke weight is deducted from this sum. Fine and coarse disintegration are then calculated by expressing the total thus obtained, and this total increased by the weight of the fraction between 1 and 3 mm, as percentages of either the weight of iron in the sample or the weight of the sample. The clearing of the barrel is checked by weighing and any correction should be transferred to the fraction below 1 mm

(7) Grinding the entire residue of the ore sample in a carefully closed ceramic ball mill for about 30 min. The ground product is divided up and a sample is extracted for analytical determination* of the degree of oxidation after test (Deg. oxd. $^{\text{test}}_{1000\,^{\circ}\text{C}}$).

By this method an estimate is obtained in a single test of the reducibility of the ore and its disintegration during reduction. The question then is: how does this test compare with practical blast-furnace operation? To give an answer it is necessary to compare the experimental values with the operating results for ores and sinter whose behaviour in the blast-furnace is known.

APPLICABILITY OF THE RESULTS

Test results from some typical burden materials are given in Table III. The values in the table show that there can be considerable differences between ores apparently identical in character. Magnetite from Grängesberg shows very low reducibility and high reduction strength, whereas lumps of hematite ore from the same mine have a slightly better reducibility, but crumble easily during reduction. Sinter from Domnarfvet shows considerably better reducibility than sinter from Oxelösund, although they are similar in composition, appearance, and reduction strength. Slagged sinter is less reducible but shows essentially better strength than black-burnt, and sinter samples picked out from different levels in a bed have also been proved to differ in quality.

Pellets of the dense type used for ore additions in open-hearth furnaces have a considerably higher reduction strength than sinter but, because of their low reducibility, they are less suitable for blast-furnace operation in Sweden, where a low coke rate is most important. By making the pellets more porous, the reducibility can be improved without lowering the reduction strength to unacceptable values. Figure 8 shows the appearance of an ore sample and the coke before and after testing.

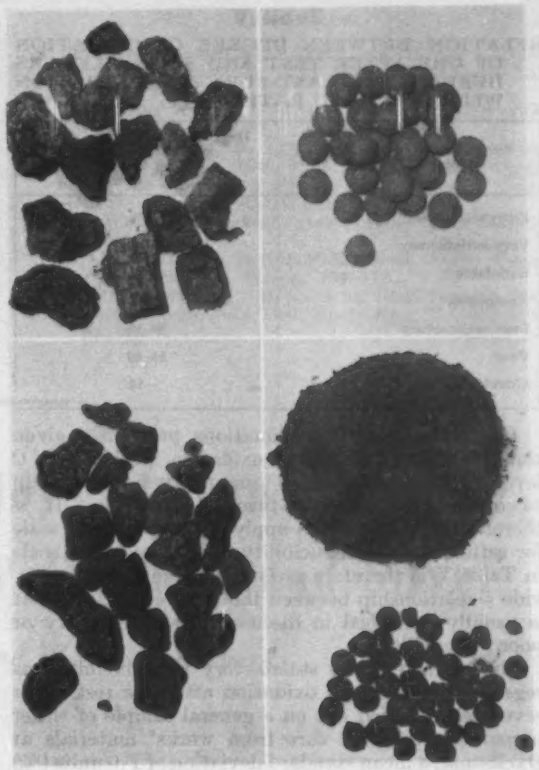


Fig. 8—Iron-ore pellets and coke: (*above*) before reduction test, (*below*) after test

Correlation between Degree of Oxidation after Test and Indirect Reduction in the Blast-furnace

Table IV gives test results for two kinds of sinter (Oxelösund KM and Domnarfvet), together with the calculated values from Table II for indirect reduction in the blast-furnace.

There is very satisfactory agreement between the test values and results obtained in practical operation. The programme for the reduction test was planned to coincide as far as possible with conditions for the production of open-hearth pig iron at Oxelösund. However, the value for the Domnarfvet sinter, which only differs from the test results by three units, confirms that a method has been found to determine in advance the behaviour of an ore during the reduction process in the blast-furnace.

* In the chemical analysis of material containing metallic iron as well as mixtures of iron oxides, the so-called iron chloride method described by Saunders[8] has been adopted. When the iron contents at different stages of valence have been determined the degree of oxidation of the sample after the test can be calculated according to the equation:

$$\text{Deg. oxd.}\,^{\text{test}}_{1000^{\circ}\text{C}} = 100\left(1 - \frac{\%\text{Fe}^{2+}}{3\,\%\text{Fe}_{\text{tot}}} - \frac{\%\text{Fe}_{\text{met}}}{\%\text{Fe}_{\text{tot}}}\right) \ldots (7)$$

Table IV

TEST RESULTS AND CALCULATED INDIRECT REDUCTION FOR SINTER

Sinter	Oxelösund KM	Domnarvet
Deg.oxd. $^{\text{bl. furn.}}_{1000\,^{\circ}\text{C}}$	54	32
Deg.oxd. $^{\text{test}}_{1000^{\circ}\text{C}}$	54	35
ΔDeg.oxd.$_{1000^{\circ}\text{C}}$	± 0	-3

Table V

RELATION BETWEEN DEGREE OF OXIDATION OF ORE AFTER TEST AND SUITABILITY AS BURDEN IN BLAST-FURNACE OPERATION WITH LOW COKE RATE

Suitability of Ore as Blast-furnace Burden	Degree of Oxidation after Reduction Test Deg. oxd. $^{test}_{1000^\circ C}$, %
Extremely good	< 35
Very satisfactory	35–40
Satisfactory	40–45
Acceptable	45–50
Less satisfactory	50–55
Poor	55–60
Unsuitable	> 60

It will be seen from equations previously given that the defined degree of oxidation at the 1000° C level can be placed in a quantitative relationship to other data on blast-furnace operation. It is therefore unnecessary to apply a discontinuous scale for estimating the reducibility of the ore. The scale in Table V is therefore given chiefly in order to provide a relationship between the test values and what is usually described in discussion as satisfactory or poor reducibility.

The method shows satisfactory reproducibility as regards the degree of oxidation after the test. For seven tests carried out on a general sample of sinter prepared with great care from works' materials at Oxelösund, a mean standard deviation of 1·0 units (%) was obtained for Deg. oxd. $^{test}_{1000\,^\circ C}$.

Effect of Ore Disintegration on Blast-furnace Operation

The successful blast-furnace operation at Oxelösund and Domnarfvet implies that the disintegration values included in Table III for the corresponding sinters must be described as acceptable. Reports[5, 7] from these blast-furnaces show, however, that in both instances scaffolding and hanging are normal phenomena. The production rate of these furnaces is not strikingly high. Experience of the addition of pellets to the burden in some Swedish blast-furnaces has shown that the furnace working has been improved, with less tendency to hanging, and that a lower pressure drop has been obtained. It is also known that Grängesberg hematite ore is definitely unsuitable as the sole iron-bearing material in a blast-furnace burden. As a result of these experiences the author has worked out the scale given in Table VI for evaluating the results of the test as regards reduction strength, and consequently the suitability of the ore for charging in blast-furnaces. The fine disintegration is regarded as the critical size.

When using Table VI it should be remembered that there are other factors which affect the mechanical conditions in the stack. Thus a burden with a high coke rate is expected to be able to carry a greater proportion of fines, and the scale could be applied more confidently than when the coke rate, owing to good reducibility, preheating of the blast to a high temperature, and optimum production rate, has been brought down to a minimum of 600 kg per ton of pig iron, at Domnarfvet, for example. A marked difference between the values for coarse and fine disintegration should suggest caution, while the opposite applies when these values are close together. The reproducibility of the method so far as disintegration is concerned is satisfactory. For the series of tests on the works sinter sample previously mentioned a mean standard deviation of 3 units (in wt-% Fe) was obtained. It has proved to be essential that sinter (and possibly also pellets) should be tested soon after production, as in most cases it becomes weaker the longer it is stored.

Table VI

RELATION OF FINE DISINTEGRATION TO SUITABILITY OF ORE FOR CHARGING IN BLAST-FURNACES

Suitability of Ore as Blast-furnace Burden	Fine Disintegration (= fines < 1 mm after test)	
	wt-% Fe	wt-% ore
Extremely good	< 40	< 20
Very satisfactory	40–50	20–25
Satisfactory	50–60	25–30
Acceptable	60–70	30–35
Less satisfactory	70–80	35–40
Poor	80–90	40–45
Unsuitable	> 90	> 45

SUMMARY

A method for programme-controlled reduction tests for blast-furnace burdens is described. Both the temperature and the composition of the reducing gas are changed according to a predetermined schedule, which corresponds as closely as possible to the conditions which apply in a blast-furnace stack. The test is terminated when a temperature of 1000° C is reached, and the degree of oxidation of the ore at this stage is taken as a measure of its reducibility. The reduction which has then taken place is considered to correspond to the indirect reduction in the blast-furnace stack.

Reduction is carried out in a barrel which rotates throughout the whole test. The quantities of fines less than 3 mm and 1 mm are taken as a measure of the disintegration of the ore during reduction. Coarse and fine disintegration are calculated by expressing these quantities as percentages of either the iron content of the ore sample or its entire weight. The fine disintegration is regarded as the critical size, and a scale is given which expresses the relationship between this value and the suitability of the ore for blast-furnace operation.

Satisfactory agreement has been found, with sinter from Oxelösund and Domnarfvet, between the reducibility determined by the tests and indirect reduction in the blast-furnace. Formulæ are given for calculating the distribution between indirect and direct reduction of the ore from working data. In investigating reduction of works' raw materials, great stress must be laid on accurate sampling so that a representative ore sample is obtained.

Acknowledgments

Work connected with the development of this reduction test began while the author was engaged in research work for Jernkontoret, and has been completed at the new metallurgical laboratory at Oxelösunds Järnverk. He wishes to thank Mr. Sven Fornander, former Director of Research of Jernkontoret, for his confidence and support and his inspiring leadership while the work was in progress, and to the technical management of the Grängesberg Company and the Oxelösund Steel Works for permission to publish this report. He also wishes to thank Professor Martin Wiberg for valuable discussions during the course of the work.

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The Constitution of Alloys of Iron with Ruthenium, Rhodium, Palladium, and Silver

By W. S. Gibson and W. Hume-Rothery

SYNOPSIS

Iron-rich binary alloys with ruthenium, rhodium, palladium, and silver have been investigated by thermal analysis in the temperature range 1380–1560° C.

The equilibrium diagrams of the systems Fe–Ru, Fe–Rh, and Fe–Pd are of the expanded γ-field type, in which the temperatures of the A_4 transformations are raised by the addition of solute. In the system Fe–Ru, the body-centred cubic (δ) iron-rich solid solution is formed by a peritectic reaction between the liquid and the face-centred cubic (γ) iron-rich solid solution. In the systems Fe–Rh and Fe–Pd, the face-centred cubic (γ) solid solution is formed peritectically from liquid and δ-solid solution. No appreciable solid solution of silver in iron at high temperatures was detected.

1555

INTRODUCTION

HELLAWELL AND HUME-ROTHERY* determined melting and freezing points of alloys of iron with transition elements of the First Long Period. The present paper describes an extension of this work to the alloys of iron with ruthenium, rhodium, palladium, and silver. Experimental methods are described in the first section, interpretation and accuracy are discussed in the second section, the experimental results are set out in the third section, and in the final section these are discussed and compared with those obtained by Hellawell and Hume-Rothery.

EXPERIMENTAL METHODS

The liquidus, solidus, and γ/δ transformation temperatures of the alloys were determined by thermal analysis. The high-vacuum furnace used for this work was the same as that used by Hellawell and Hume-Rothery.

The furnace consisted of an alumina tube sealed at each end and having a platinum-wound resistance furnace outside it. A thermocouple sheath was fitted through the upper seal, and the crucible assembly was introduced through the lower seal. This assembly could be moved in relation to the furnace tube by external means, so that the alloy was either at the centre or in a cold region of the furnace. The whole apparatus could be evacuated or filled with purified argon or hydrogen.

The ingots were contained in alumina crucibles, and alumina thermocouple sheaths were used throughout. When practicable, the melts were deoxidized by admitting purified hydrogen; the gases were removed before proceeding with thermal analysis.

Temperatures were measured by thermocouples inserted into the alumina sheath. Two types were used, the standard Pt/Pt–13%Rh and a Pt–2%Rh/Pt–13%Rh couple. Each was calibrated frequently at the freezing point of nickel (1453° C), to which all temperatures were referred.

Materials

For the present work, *H* iron of approximately 99·96% purity was used, kindly presented by the British Iron and Steel Research Association. Palladium, rhodium, and ruthenium were supplied by

* B.I.S.R.A. unpublished Report. MG/A/16/56, and *Phil. Trans. Roy. Soc.*, 1957, Series A, vol. 249, p. 417.

Paper MG/A/89/58 of the Alloy Steels Committee of the B.I.S.R.A. Metallurgy Division, received on 27th February, 1958. The views expressed are the authors', and are not necessarily endorsed by the Committee as a body.

Mr. Gibson is a research student at the University of Oxford, where Dr. Hume-Rothery is Professor of Metallurgy.

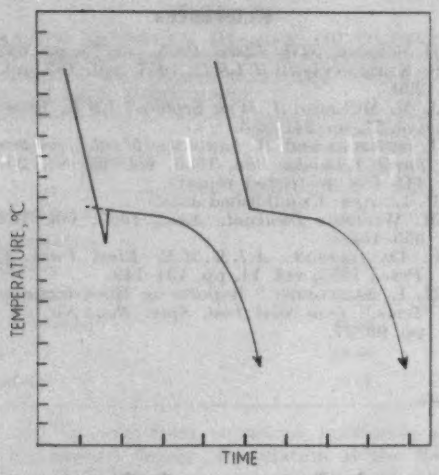

Fig. 1—Cooling curves with and without supercooling

Johnson Matthey and Co., Ltd., in the form of powders, the analyses of which were :

	Element	Wt-%
Palladium	Rh	0·005
	Pt	0·02
	Ag	0·01
	Cu	0·0001
	Fe	0·001
		0·0361
Rhodium	Si	0·02
	Pd	0·01
	Pt	0·005
	Ag	0·005
	Sn	0·005
	Fe	0·005
	Cu	0·005
	Ni	0·0005
		0·0555
Ruthenium	Pt	0·005
	Pd	0·003
	Rh	0·003
	Au	0·002
	Cu	0·001
	Fe	0·0004
	Mn	0·0001
	Si	0·001
	Ag	0·003
		0·0185

No analyses for oxygen or nitrogen had been carried out upon these powders because such gases were adsorbed in variable amounts depending largely on storage conditions. The manufacturers recommended deoxidation of the palladium before use.

Assay silver bar of 99·99% purity was used in the preparation of iron–silver alloys.

Microscopical Examination of Alloys

The furnace-cooled ingots were prepared for microscopical examination and a count of the oxide particles in a given area was made. In each alloy series the ingot having the highest oxide-particle density was analysed for oxygen by vacuum-fusion methods.

Analysis of Alloys

The palladium series was analysed by Johnson Matthey and Co., Ltd. Palladium was determined in each alloy, with the exception of one, in which both iron and palladium were determined. One half of one of the alloys was sent to the laboratories of the United Steel Companies Ltd. at Rotherham for vacuum-fusion analysis for oxygen, and thanks are due to Dr. K. W. Andrews for undertaking this work.

The ruthenium and the rhodium alloys were analysed at the B.I.S.R.A. Sheffield laboratory, each being analysed for solute element only. One alloy of each series was analysed for oxygen by vacuum fusion. Thanks are due to Mr. K. Speight for the high accuracy of the results which he obtained.

INTERPRETATION OF RESULTS

The accuracy of the equilibrium diagrams depends upon (*a*) accuracy in temperature measurement, (*b*) the interpretation given to the cooling curves, and (*c*) accuracy in composition.

Accuracy in Temperature Measurement

It has been estimated by Hellawell and Hume-Rothery that the present methods render temperature measurement in the range 1350–1550° C liable to errors of the order of ±1–2° C when referred to a melting point for nickel of 1453° C. The accuracy should increase slightly in the region of the nickel point.

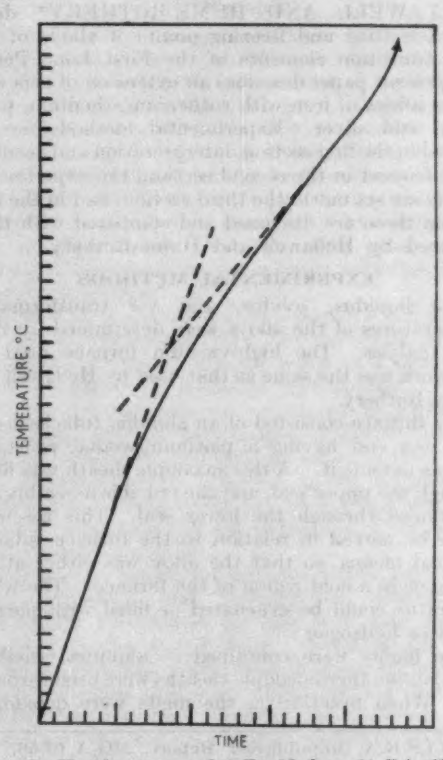

Fig. 2—Heating curve for Fe–10·3 at-% Pd alloy

Between calibration and actual temperature measurement, there is probably some deterioration of the thermocouple itself. For this reason calibration was carried out frequently. Differences between two such calibrations rarely exceeded 2° C, and more often were less than 1° C. Appropriate corrections were applied to the arrest temperatures, based on the deviation of the couple from 1453° C during the last calibration.

Interpretation of Cooling Curves

Liquidus

The temperature range over which a metal or alloy freezes may be large or small. In pure nickel a prolonged arrest lasting for 10–20 min in a 50–100-g melt occurs on freezing. Heating curves show a well defined arrest, and the freezing and melting temperatures agree to within a few tenths of a degree centigrade. In *H* iron a wider range* is observed, and the temperature obtained from the heating curve arrest is about 1° C lower than that from the cooling curve.

On cooling curves slight rounding of the curve is shown before an arrest is properly established and, as in the work of Hellawell and Hume-Rothery, the true liquidus point was taken to be that given by extrapolating the linear portions of the curve before and after the arrest to their intersection. When the change of gradient of the cooling curve is sharp at the liquidus, the accuracy of interpretation is high. It is thought that errors of not more than $\pm 0{\cdot}5$° C are introduced in favourable cases of pure metals and of iron-rich alloys. This applies to the liquidi of the iron–ruthenium and iron–rhodium alloys in which the depression of freezing point and the width of the two-phase (liquid + solid) region are both small.

In a 3·6 at-%Pd alloy, the freezing range is about 25° C and, owing to slight indistinctness in the arrest, errors of ± 1° C are thought to be introduced when interpreting this type of curve. This applies to the liquidi of all the alloys of the iron–palladium series.

* Cooling curves and heating curves for *H* iron have been published by Hellawell and Hume-Rothery.

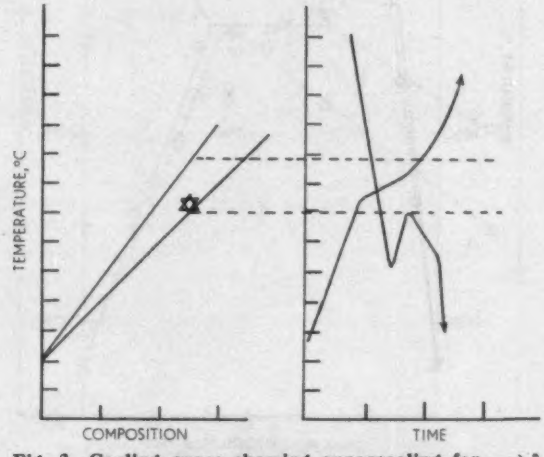

Fig. 3—Cooling curve showing supercooling for $\gamma \rightleftharpoons \delta$ transformation in solid state

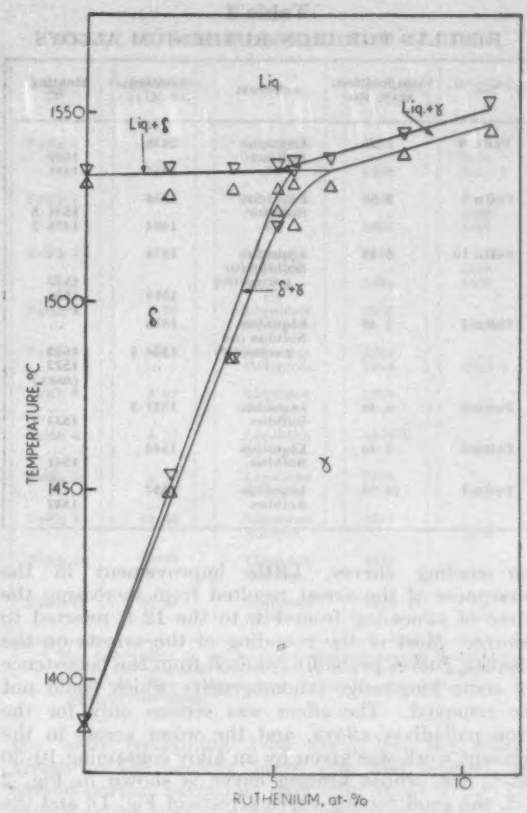

Fig. 4—Phase diagram of Fe–Ru alloys

Further slight errors resulting from temperature gradients in the melt must be added to the errors in interpretation. It is not possible to claim gradients of less than 1° C throughout the alloy at the arrest temperature.

Two to three degrees of supercooling frequently took place, normally followed by recalescence. Where supercooling is limited to 2–3° C, it is not thought to affect the interpreted arrest temperature (Fig. 1).

Solidus

When fully solidified, each alloy was homogenized in the single-phase δ-region of the equilibrium diagram for about 12 h, in order to remove coring introduced during solidification. The solidus was obtained from the heating curve at the melting point of the alloy.

In *H* iron the solidus is about 1° C below the freezing point, probably because of the small amounts of impurity present. In the iron-rich alloy, this freezing range of 1° C is probably added to the freezing range of the alloy. It is probable that the addition of 1° C to the solidus points of these alloys more nearly approaches the true solidus points of the pure binary alloys.

In general, solidus arrests on heating curves were less distinct and more rounded than liquidus arrests

Table I
RESULTS FOR IRON–RUTHENIUM ALLOYS

No.	Composition, at-% Ru	Arrest	Cooling, °C	Heating, °C
FeRu 9	2·26	Liquidus	1535	...
		Solidus	...	1530
		γ/δ	1453	1451
FeRu 3	3·96	Liquidus	1534	...
		Solidus	...	1531·5
		γ/δ	1484	1486·5
FeRu 10	5·10	Liquidus	1535	...
		Solidus (or peritectic)	...	1522
		γ/δ	1519	1526
FeRu 2	5·48	Liquidus	1536	...
		Solidus (or peritectic)	1534·5	1533
		γ/δ	...	1522 (max)
FeRu 5	6·48	Liquidus	1537·5	...
		Solidus	...	1532·5
FeRu 6	8·46	Liquidus	1544	...
		Solidus	...	1541
FeRu 7	10·76	Liquidus	1552	...
		Solidus	...	1547

on cooling curves. Little improvement in the sharpness of the arrest resulted from increasing the time of annealing from 1 h to the 12 h referred to above. Most of the rounding of the arrests on the heating curves probably resulted from the persistence of some long-range inhomogeneity which could not be removed. The effect was serious only for the iron–palladium alloys, and the worst arrest in the present work was given by an alloy containing 10·30 at-% Pd, whose heating curve is shown in Fig. 2 (cf. the good cooling curve arrests of Fig. 1), and the error involved is discussed below. Rounding of an arrest on a cooling curve may also result from temperature gradients between the inside and outside of the ingot during the heating process, but the extrapolation method tends to correct most of the error from this source. On the other hand, when rounding of an arrest occurs as a result of uneven composition of an ingot, the extrapolation method will always give too low a solidus point, and this source of error is inherent in the method.

γ/δ Transformation Temperatures

A smaller latent heat accompanies the reaction

$$\gamma_{Fe} \xrightarrow[\Delta H = 1{\cdot}8\ \text{cal/g}]{} \delta_{Fe}$$

than the reaction

$$\delta_{Fe} \xrightarrow[\Delta H = 65\ \text{cal/g}]{} \text{Liquid}.$$

Consequently arrests on heating and cooling through the transformation are shorter and usually less distinct. The change from δ_{Fe} to γ_{Fe} has a pronounced tendency to supercool up to 5° C and, because of the small latent heat involved, recalescence does not always bring the specimen back to the transition temperature (Fig. 3). It is unfortunate that this transformation cannot be initiated by external means apart from cooling. Both heating and cooling curves are influenced adversely by inhomogeneity, like the solidus. Temperature gradients are also much greater during these arrests than during either a liquidus or a solidus because the shorter duration of the arrest fails to bring the ingot to a uniform temperature.

In view of the foregoing, it is not proposed to estimate the accuracy of $\delta/\delta + \gamma$ and $\gamma/\gamma + \delta$ points, but it is suggested that errors do not exceed ±5° C and are probably well within this in some cases.

Accuracy in Determination of Composition

Loss of iron by volatilization from the molten alloy was found to occur somewhat readily, and weight losses up to 2 g were encountered in some of the alloys. Most of the loss took place during the preliminary melting, and particularly during the removal of hydrogen after deoxidation. This often took up to 1 h before a satisfactorily low pressure was obtained. Some further loss probably took place during the final melting of the alloy (solidus heating curve), but the alloy was normally solidified rapidly after removing the thermocouple sheath. The synthetic* composition of each alloy was adjusted according to the weight loss, assuming the loss to be iron. A comparison between these adjusted compositions and the analysed compositions showed that some loss of solute usually took place, although most of the loss was iron.

In view of these changes in composition, the equilibrium diagrams have been plotted using the analysed

* Synthetic composition here refers to the composition calculated from the weights of pure metals used in preparing the alloy.

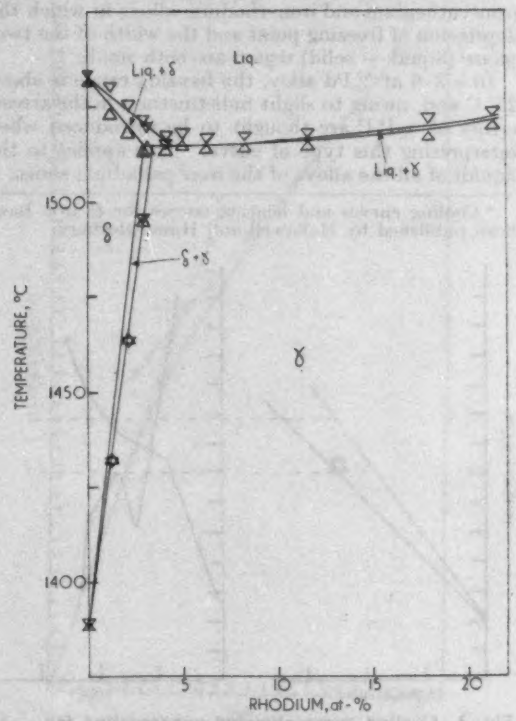

Fig. 5—Phase diagram of Fe–Rh alloys

compositions, as these probably more nearly approach the values obtaining during the thermal analysis.

EXPERIMENTAL RESULTS

Pure Iron

The freezing point of *H* iron was determined as 1533° C and the γ/δ transformation temperature was found to be 1389° C. These results are the same as those obtained by Hellawell and Hume-Rothery.

Iron–Ruthenium

The results are set out in Table I and Fig. 4. Because of possible gaseous contamination of the ruthenium sponge, the molten alloys were treated with dry hydrogen and then the thermal analysis was carried out *in vacuo*.

The equilibrium diagram has a restricted δ-field and a peritectic reaction at 1536° C as follows :

Liquid (5·0%)* + Solid γ (6·5%) $\rightleftharpoons$ Solid δ (5·5%).

No definite arrest attributable to the peritectic was obtained.

In Fig. 4 the δ-liquidus and solidus are drawn almost horizontal, although the solidus arrest points in the region of 2–4 at-% Ru are about 2·5–5° C below the curve. The alternative form of diagram with a minimum in the solidus would require also a minimum in the liquidus ; this appears most improbable, because the liquidus arrests on cooling curves were clear and could be located accurately, as they were almost as well defined as those for the *H* iron. For the alloy containing 3·96 at-% Ru, the solidus arrest on the heating curve was well defined, the curved portion extending over only about 3° C. The extrapolation method gave a solidus point of 1531·5° C and a liquidus point of 1534° C from the cooling curve. If the solidus point is raised by 1° C to allow for the difference between heating and cooling curve arrests for *H* iron (*see* p. 245), this implies a freezing range of only 1·5° C and confirms the nearly horizontal curves in Fig. 4. The solidus arrest for the alloy containing 2·26 at-% Ru was less definite, and the extrapolated liquidus and solidus points were 1535° and 1530° C, but the result for the 3·96 at-% alloy is to be preferred.

Alloy FeRu 3 was analysed for oxygen by vacuum fusion ; it contained 0·0034% O_2. The oxide particle count suggested that this alloy contained somewhat more oxygen than any of the remaining ingots.

Iron–Rhodium

The results are set out in Table II and Fig. 5. Like the ruthenium series, these alloys were treated with hydrogen and then thermal analysis was carried out *in vacuo*.

Alloy FeRh 3 was analysed for oxygen by vacuum fusion ; it contained 0·013% O_2. The oxide particle count suggested that this alloy contained about half as much oxygen again as any of the remaining ingots.

The equilibrium diagram is of the open γ-field type and there is a peritectic at 1515° C at which the following reaction occurs :

Solid δ (2·9%) + Liquid (4·3%) $\rightleftharpoons$ Solid γ (3·4%).

Table II

RESULTS FOR IRON–RHODIUM ALLOYS

No.	Composition, at-% Rh	Arrest	Cooling, °C	Heating, °C
FeRh 7	1·17*	Liquidus	1529	...
		Solidus	...	1524
		γ/δ	1430	1433·5
FeRh 1	2·11	Liquidus	1524	...
		Solidus	...	1520
		γ/δ	1462	1465
FeRh 3	2·87	Liquidus	1520	...
		Solidus	...	1515
		γ/δ	1494	1496
FeRh 4	3·06	Liquidus	1519	...
		Peritectic	...	1516
FeRh 2	4·13	Liquidus	1516	...
		Peritectic	1514	1514·5
FeRh 9	5·02	Liquidus	1517	...
		Solidus	...	1516
FeRh 6	6·17	Liquidus	1515·5	...
		Solidus	...	1515
FeRh 5	8·12	Liquidus	1516	...
		Solidus	...	1515
FeRh 8	11·62	Liquidus	1517	...
		Solidus	...	1516
FeRh 10	17·99	Liquidus	1520	...
		Solidus	...	1518
FeRh 11	21·34	Liquidus	1522	...
		Solidus	...	1521

* This figure refers to the maximum rhodium content as calculated from the synthetic composition (1·02%) and the weight loss observed. The analysed figure of 1·38% was high owing to analysis difficulties.

* Percentages are atomic unless otherwise stated.

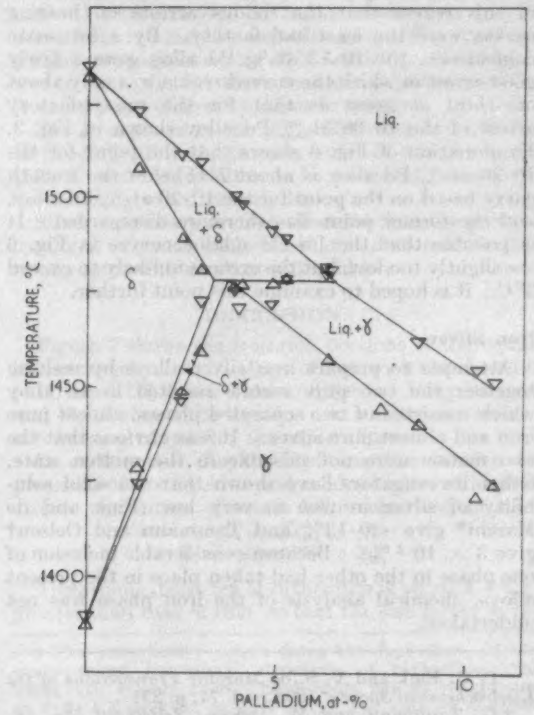

Fig. 6—Phase diagram of Fe–Pd alloys

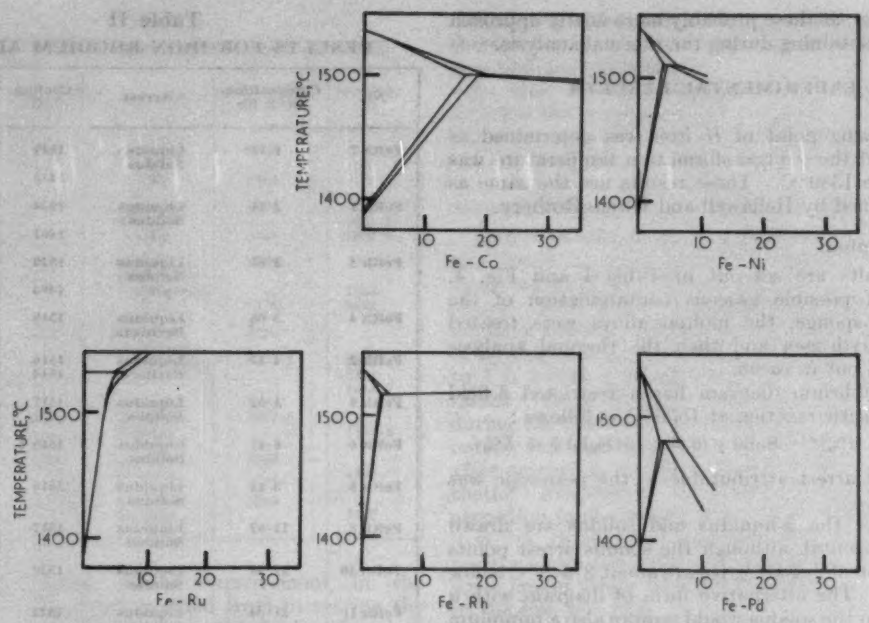

Fig. 7—Phase diagrams for iron-rich alloys with Group VIII Solute Elements in the First and Second Long Periods

After the peritectic, the γ-liquidus and solidus remain more or less constant and at 16% their respective figures are 1516° C (liq.) and 1515° C (sol.). Between the peritectic composition and 16 at-% Rh, the liquidus arrests on cooling curves were very well marked and almost as sharp as those for *H* iron, in agreement with the almost horizontal portion of the equilibrium diagram. The peritectic form for the diagram requires the γ-liquidus and solidus to fall initially after the peritectic horizontal. It is necessary therefore to postulate a minimum in these curves in this region, although this is probably too shallow to be detected by present methods.

Iron–Palladium

The results are set out in Table III and Fig. 6. It was not found practicable to treat the molten alloys with hydrogen as this could not easily be removed later. Since the manufacturers recommended deoxidation, the powder was heated in hydrogen to 900° C for ½ h and then *in vacuo* for 1 h. This sponge was then used in the preparation of alloys FePd 7 to FePd 13 inclusive. The other six alloys were prepared from untreated sponge, and one of these alone was treated with hydrogen in the molten state. In the latter case it took 2–3 h to remove all the absorbed hydrogen before thermal analysis could begin.

Half of alloy FePd 4 was analysed for oxygen ; the analysis showed 0·031% O_2 present. This alloy contained more than twice the oxide particle density of any of the other alloys.

The equilibrium diagram is of the open γ-field type. The δ-liquidus and solidus fall steeply to a peritectic at 1478° C at which the following reaction takes place :

Solid δ (3·3%) + Liquid (6·5%) $\rightleftharpoons$ Solid γ (3·7%).

The peritectic was clearly established by thermal arrests on cooling and on heating in five of the alloys.

After the peritectic the liquidus and solidus continue to fall steeply. As explained on p. 246, it was in this region that the solidus arrests on heating curves were the least satisfactory. By a fortunate coincidence, the 10·73 at-% Pd alloy gave a fairly good arrest in which the curved region was only about one-third as great as that for the unsatisfactory arrest of the 10·30 at-% Pd alloy shown in Fig. 3. Examination of Fig. 6 shows that the point for the 10·30 at-% Pd alloy is about 7° C below the smooth curve based on the point for the 10·30 at-% Pd alloy, and the former point was therefore disregarded. It is possible that the Fe–Pd solidus curves in Fig. 6 are slightly too low, but the error is unlikely to exceed 3° C ; it is hoped to examine this point further.

Iron–Silver

Attempts to prepare iron–silver alloys by melting together the two pure metals resulted in an alloy which consisted of two separated phases, almost pure iron and almost pure silver. It was obvious that the two metals were not miscible in the molten state. Other investigators have shown that the solid solubility of silver in iron is very low (Fink and de Marchi* give $<0{\cdot}13\%$ and Tammann and Oelsen† give 3×10^{-4} %). Because considerable inclusion of one phase in the other had taken place in the present alloys, chemical analysis of the iron phase was not undertaken.

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* C. G. Fink and V. S. de Marchi, *Transactions of the Electrochemical Society*, 1938, vol. 74, p. 271.

† G. Tammann and W. Oelsen, *Zeitschrift für Anorganische Chemie*, 1930, vol. 186, p. 257.

Table III
RESULTS FOR IRON–PALLADIUM ALLOYS

No.	Composition, at-% Pd	Arrest	Cooling, °C	Heating, °C
FePd 11	1·38	Liquidus	1521	...
		Solidus	...	1509
		γ/δ	1423	1430·5
FePd 1	2·48	Liquidus	1510	...
		Solidus	...	1490·5
		γ/δ	1445	1450
FePd 3	3·01	Liquidus	1508	...
		Solidus	...	1485·5
		γ/δ	1471	1461
FePd 9	3·88	Liquidus	1499	...
		Peritectic	1474	1477·5
FePd 4	4·09	Liquidus	1497	...
		Peritectic	(1469)	1478·5
FePd 2	4·83	Liquidus	1489·5	...
		Peritectic	(1470·5)	1478·5
FePd 5	5·24	Liquidus	1488	...
		Peritectic	1477	1480
FePd 10	6·33	Liquidus	1479·5	...
		Solidus (γ)	...	1459
		Peritectic	1478	...
FePd 6	6·40	Liquidus	1479	...
FePd 7	7·78	Solidus	...	1446
FePd 12	8·74	Liquidus	1461	...
		Solidus	...	1442
FePd 13	10·30	Liquidus	1453·5	...
		Solidus	...	1422·5
FePd 8	10·73	Liquidus	1450	...
		Solidus	...	1426

Two alloys were melted. Melting was carried out under 1 atm pressure of argon to suppress loss of silver from the melt by volatilization. The synthetic weight compositions were 30% and 50%. The object was to find whether there was any depression of the freezing point of iron by silver in solution.

The iron phase in the 30% alloy froze at 1530° C. In the 50% alloy the freezing point of this phase was 1533° C, and this result is to be preferred because the supercooling was distinctly less.

Silver does not therefore affect the freezing point of iron, and it seems probable that it does not dissolve to any appreciable extent in liquid iron.

DISCUSSION

Figure 7 shows the iron-rich portions of the equilibrium diagrams of the alloys of iron with the elements of Group VIII in the First and Second Long Periods, and Fig. 8 shows the liquidus and solidus curves, and the freezing ranges for the same alloys.

In each period, for the δ-phases, the relative depressions of the liquidus and solidus curves at a given atomic percentage of solute follow clear sequences :

$$\text{Fe } (=0) < \text{Co} < \text{Ni}$$
$$\text{Ru } (\sim 0) < \text{Rh} < \text{Pd}$$

The atomic diameter of ruthenium is about 4–7%‡ greater than that of iron, so that the size factor in the system Fe–Ru is very favourable. In this system the depressions of the δ-liquidus and δ-solidus curves are too small to be measurable and the curves are drawn as almost horizontal lines in Figs. 7 and 8. The melting point of ruthenium (2500° ± 100° C) is much greater than that of iron, and it is therefore possible that the almost horizontal δ-liquidus and δ-solidus curves are the result of the rise to be expected from the higher melting solute being counterbalanced by a fall due to the lattice distortion. This would, however, be a remarkable coincidence, and the diagram suggests clearly that the δ/liquid equilibrium is unaffected when solute and solvent are in the same Group of the Periodic Table, and the size factor is favourable. The forms of the curves mean that ruthenium affects the free energies of liquid and solid (δ) solution in almost the same way.

For rhodium and palladium the size factors relative to iron are about 6% and 8% respectively, and are thus still very favourable. The relative depressions Ru < Rh < Pd are thus in the same order as the differences between the Group numbers of solvent and solute, and in the same order as the size factors, in so far as these can be estimated from the atomic diameters. The relative depressions Rh > Co and Pd > Ni are also in the order of the size factors.

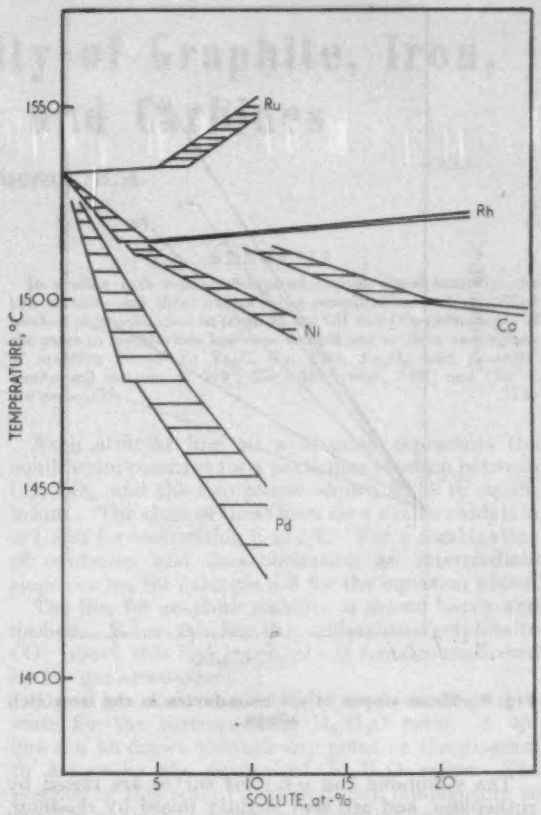

Fig. 8—Freezing ranges for iron-rich alloys with Group VIII Solute Elements in the First and Second Long Periods

‡ The uncertainty arises from the fact that, in the close-packed hexagonal structure of ruthenium, the axial ratio is only 1·58. Each atom has six neighbours at 2·64 kX and six at 2·70 kX. The smaller distance gives a size factor of + 4% and the mean distance one of + 7%.

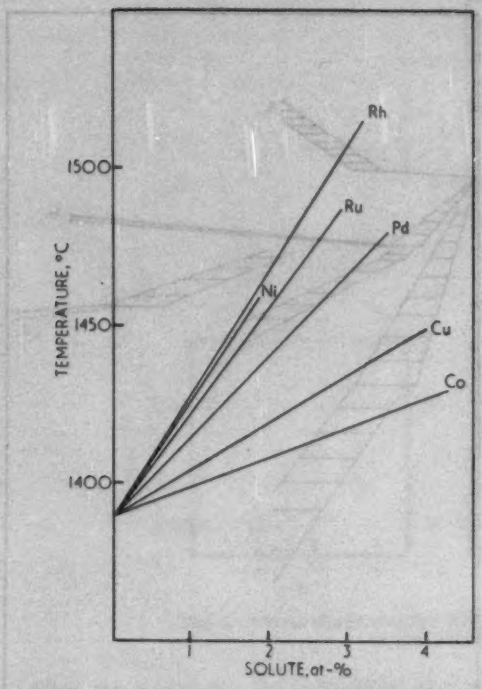

Fig. 9—Mean slopes of γ/δ boundaries in the iron-rich alloys.

The γ-liquidus and γ-solidus curves are raised by ruthenium, and are very slightly raised by rhodium, but the effect of the latter is very small, and an increase in rhodium content from 5 to 21 at-% only produces a rise of about 6–7° C. This is again very curious and means that, for a considerable range of composition, the free energies of liquid and γ-solid solutions are affected in the same way by rhodium. The γ-liquidus and γ-solidus curves are depressed by palladium so that, if a rise in temperature is regarded as a negative depression, the relative depression produced by equal atomic percentages of solute is again in the order Ru < Rh < Pd. The Fe–Pd diagram is characterized by a much smaller change in direction of the curves at the peritectic temperature.

Examination of Fig. 7 shows that the Fe–Rh γ-liquidus and γ-solidus curves are higher than would be expected from a regular sequence with the remaining systems.

The Melting Point of γ-Iron

Hellawell and Hume-Rothery pointed out that for some purposes it was useful to regard the γ-liquidus and γ-solidus curves as proceeding from a hypothetical melting point of pure γ-iron, which they placed at 1520° C. The present narrow freezing range for γFe–Ru and the almost horizontal γFe–Rh liquidus and solidus curves enable this hypothetical temperature to be estimated as being about 1514° C, referring to a freezing point of 1533° C for pure δ-iron.

The γ-stabilizing Powers

Ruthenium, rhodium, and palladium all give rise to equilibrium diagrams of the expanded γ-field type. In so far as the γ-stabilizing power of the solute is measured by the slope of γ/δ boundaries, the present work shows the elements to exert effects in the order Pd < Ru < Rh.

The high Fe–Rh γ-solidus curve is thus parallelled by a high stabilization of γ in the γ/δ equilibrium. For these elements, therefore, rhodium has an abnormally high stabilizing effect for the γ-solid solution. This is in contrast to the elements of the previous Period, for which the γ-stabilizing powers are in the order

$$\text{Fe} < \text{Co} < \text{Ni} > \text{Cu}$$

and it is nickel in Group VIIIc which has the greatest effect (Fig. 9). In each Period the γ-stabilizing power reaches a maximum in Group VIII, and the increased size factor for the solutes in the Second Long Period appears to move the position at which the maximum appears one step back in the Periodic Table.

It is known that on passing from Fe → Co → Ni and from Ru → Rh → Pd, the (3d) and (4d) subgroups of electron orbitals are rapidly filling up, and giving rise to electron clouds which are more and more like those of hard spheres. On reaching copper and silver the $(3d)^{10}$ and $(4d)^{10}$ subgroups may be regarded as completely filled, and the electron clouds are smaller than those of the preceding elements, nickel and palladium. Since the face-centred cubic structure of γ-iron is one analogous to the close packing of spheres, it is perhaps possible to understand why in the series Fe–Co, Fe–Ni, and Fe–Cu, where the atoms are of the same size, the γ-stabilizing power diminishes when the (3d) core shrinks on passing from Ni → Cu. It also explains why with the larger atoms of ruthenium, rhodium, and palladium, the maximum γ-stabilizing power is moved backwards from Group VIIIc to VIIIb, because the repulsive forces resulting from the overlapping of the atomic cores will become greater as the (4d) shell fills up and, if it becomes too great, the large solute atom may be accommodated more easily in the relatively open structure of the body-centred cubic δ-iron.

Acknowledgments

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Conditions for Stability of Graphite, Iron, and its Oxides and Carbides

By D. I. Cameron, B.A.

SYNOPSIS

In dealing with iron, carbon, and oxygen simultaneously, the two carbides and three oxides cause complications. A simplified method of presentation in terms of the CO and CO_2 percentages of the gases in equilibrium has been worked out to show the regions of stability for Fe_3C, Fe_2C, Fe, FeO, Fe_3O_4, and graphite. Isothermal sections at 500°, 550°, 600°, 650°, 700°, and 750° C are presented. 1510

REACTIONS BETWEEN STEEL and any gas atmosphere involve the transfer of carbon or oxygen or both. The equilibrium conditions for these reactions can be determined in terms of the carbon or oxygen potential[1,2] and it is possible to superimpose a carbon potential diagram on an oxygen potential diagram or vice versa. However, the position and even the size of the superimposed diagram varies with the CO and CO_2 pressures involved. This method of presentation proves much too complex for ready interpretation. The difficulty arises because there is not one link but two links between the oxygen and carbon potential diagram, and both are gases, CO and CO_2. In the system there is also one variable too many for convenience, which makes it desirable to hold one of the variables constant.

After examining a number of possibilities the simplest approach seemed to be to prepare a series of isothermal equilibrium diagrams for a range of relevant temperatures, and to express the variations in gas composition by means of a simple plot of the CO/CO_2 content on a log-log scale. The ranges of gas composition which are in equilibrium with the different possible solid phases can then be easily indicated.

In its simplest form this is done in the conventional diagram showing the CO/CO_2 ratio which is the boundary between iron and iron oxide, or the CO^2/CO_2 ratio which is the boundary between carburizing and decarburizing conditions. The present method of presentation also shows the region of stability for two of the oxides of iron and for both carbides, for graphite and metallic iron over the range of practical gas compositions.

The calculation which has been necessary in preparing these diagrams is given in the Appendix.

Basis of the Diagrams

Any of the possible reactions between iron, its oxides, or its carbides can be expressed in terms of the transfer of carbon and oxygen. Moreover, the transfer can always be expressed in terms of CO and CO_2 as the only gases present, e.g.

$$Fe_3C + 5\,CO_2 = Fe_3O_4 + 6\,CO.$$

From a knowledge of the thermodynamic data for a basic set of equations, the equilibrium constants for all possible reactions in terms of $CO + CO_2$ have been derived and used to prepare the isothermal sections (Figs. 1*a–f*).

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Mr. Cameron is Research Superintendent at Lysaght's Central Research Laboratory, Newcastle, New South Wales, Australia.

Each straight line on a diagram represents the equilibrium constant for a particular reaction between CO, CO_2, and the two phases shown to be in equilibrium. The slope of these lines for a simple oxidation is 1 and for carburizing it is 1/2. For a combination of oxidation and decarburization an intermediate slope occurs, for example 5/6 for the equation above.

The line for graphite stability is shown heavy and dashed. Below this line CO_2 will oxidize graphite to CO; above this line graphite will remain unaffected by the gas atmosphere.

There has also been included in each diagram a scale for the corresponding H_2/H_2O ratio. A 45° line can be drawn through any point on the diagram to determine the equivalent H_2/H_2O ratios. The position of this scale varies from one temperature to another as the water-gas equilibrium constant varies.

Discussion of the Regions

In general, the top left-hand corner of the diagram is the region for stability of carbides, and the bottom right-hand corner for oxides. Between the two lies an area which increases with rising temperature, within which metallic iron is stable. The Fe_2O_3 region lies well below the Fe_3O_4/FeO line and does not appear on any of the diagrams. In round figures the CO/CO_2 ratio for the Fe_2O_3/Fe_3O_4 line is 0·0001, so that a trace of CO in CO_2 is enough to prevent the formation of Fe_2O_3.

In the diagram for 600°C (Fig. 1*c*) a section at 4% CO_2 can be taken for convenience. With both Fe_2C and Fe_3C present the equilibrium gas will be 4% CO_2 and 30% CO. With only Fe_2C present CO must be over 30% and with only Fe_3C the CO must be between 8 and 30%. At 4% CO_2 and 8% CO both Fe and Fe_3C are the equilibrium solid phases and so on.

In particular, the range of gas compositions in equilibrium with metallic iron is quite narrow. If the CO_2 increases, the range for CO becomes narrower still, the triple point for Fe, Fe_3C, and FeO occurring at about 11% CO_2 and 13% CO at 600°C. For any higher CO_2 content than this, there is no CO content that will make equilibrium with metallic iron possible; the oxide then converts direct to the carbide.

In addition to the iron-bearing phases, graphite

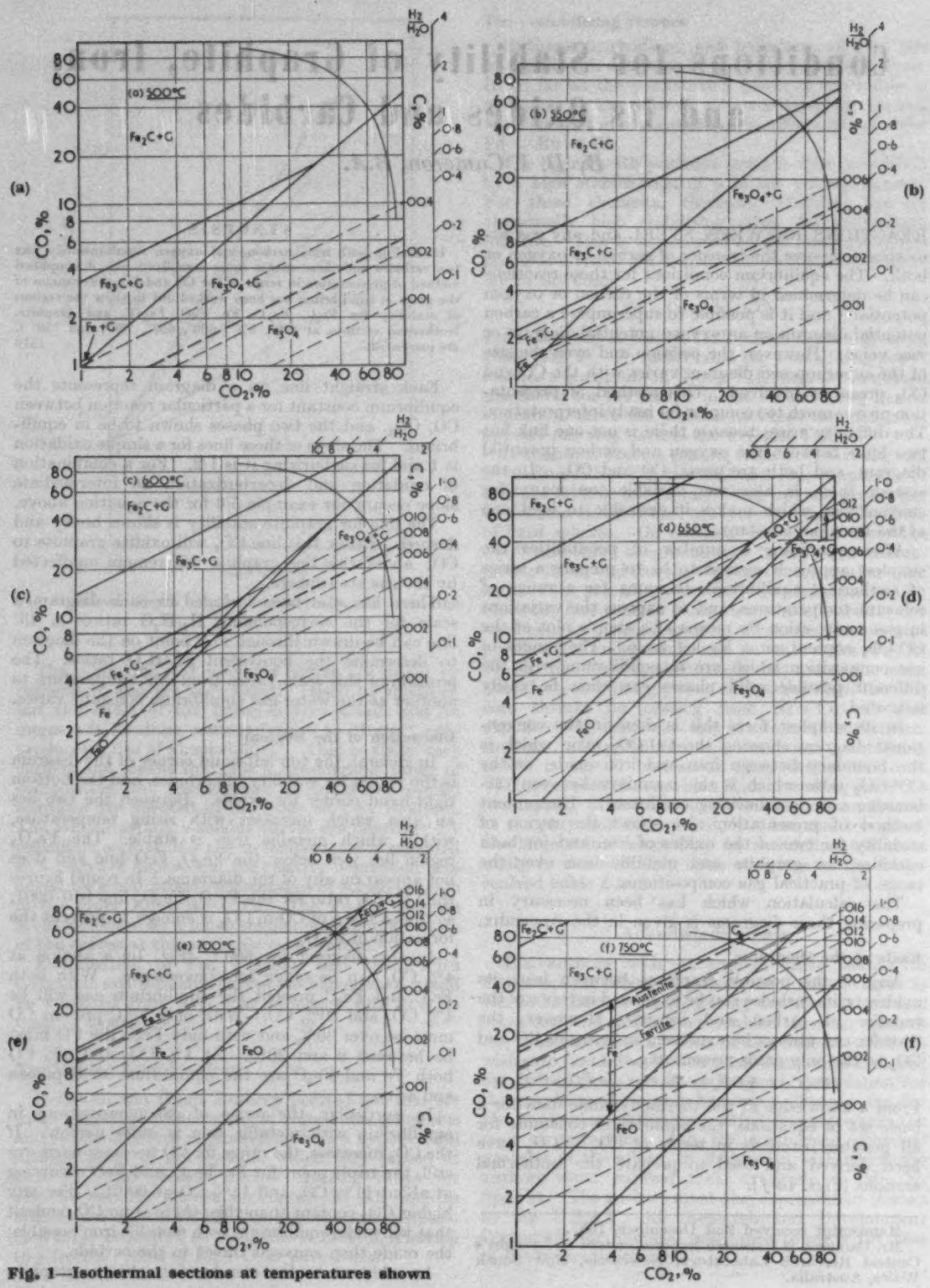

Fig. 1—Isothermal sections at temperatures shown

can also be in equilibrium with compositions of higher carbon potentials than represented by the heavy dashed graphite line. For increasing carbon potentials of the gas above the graphite line, it becomes more likely that the gas will deposit graphite, but usually in this temperature and pressure range some form of surface catalyst is required. The equilibrium diagram cannot show whether the deposition will occur, it can only show if it is possible from energy considerations. If the catalysts themselves have regions of stability on the CO/CO_2 diagram, this information may be used.

Recent work[3,4] on the decomposition of CO confirms that the rate of graphite deposition depends very much on experimental conditions, e.g. purity of gas, rate of gas flow, amount and nature of catalyst, and presence of other gases such as H_2 and H_2O. In such experiments starting with CO, the CO_2 content is not easily controlled and would usually be less than the equilibrium value for the solid components by an indeterminate amount. There is evidence[4] that the Hägg carbide (Fe_2C or $Fe_{20}C_9$) and cementite formed by the direct carburizing of iron oxide are catalysts, but further experiments over a range of conditions are needed to confirm if these are the only ones.

Carbon Content of Ferrite

Lines have been drawn on the diagram to show the equilibrium carbon contents in ferrite for saturation with Fe_3C, and also lower values down to 0·001% carbon. The carbon content in equilibrium with graphite can also be read. These values have been taken from Darken and Gurry.[5]

With a continuous flow of gas past an iron surface, the equilibrium carbon content can be found from the diagrams, if the gas composition is known. When steel sheets are processed as tight coils or in a stack, the gas between the sheets rapidly comes to equilibrium with the components present and reaction usually ceases. However, reactions can proceed if the components can react with one another using the gas phase as a carrier, or if some mechanism is present for continuous removal of one or more components of the gas phase. Typical possibilities are: (*a*) use of partial vacuum to reduce partial pressures, (*b*) generation of an equilibrium gas with total pressure over 1 atm, when it will blow off, (*c*) absorption between the sheets, e.g. of CO_2 by a lime coating.

On the CO/CO_2 diagram the line representing 1 atm total pressure for $CO + CO_2$ is of practical significance, in relation to the possibilities of continuous blow-off. This curved line has been drawn in the upper right part of the diagrams. It has been used to derive the information given in Table I, which shows the limit of decarburization for iron when decarburized at selected temperatures in the presence of the two iron oxides. Conditions are that $CO + CO_2$ equals 1 atm by self-generation, and the source of available oxygen is from the component pair indicated. For Fe_3O_4/FeO, for example, the Fe_3O_4 is the source of oxygen as it converts to FeO.

If the $CO + CO_2$ pressure at equilibrium is less than 1 atm, the reaction will cease when the equilibrium partial pressures of CO and CO_2 have been reached. This condition is marked ND (Non-decarburizing) in Table I. If the $CO + CO_2$ pressure at equilibrium exceeds 1 atm, continuous generation of gas can occur till either the carbon potential drops to equilibrium with the source of oxygen, or the latter is all used up.

Table I
DECARBURIZATION LIMIT FOR CARBON IN IRON

$CO + CO_2 = 1$ atm	Source of oxygen as shown	
°C	FeO/Fe, %	Fe_3O_4/FeO, %
750	0·014	0·005
700	0·014	0·006
650	ND	0·010
600 and lower	ND	ND

ND = Non-decarburising

Table I shows that oxygen at the Fe_3O_4/FeO potential can decarburize to a lower value than FeO/Fe, and that decarburizing can take place at a lower temperature. The difference between the two oxides becomes more marked with increasing temperature.

In practice, the oxygen available from Fe_3O_4 can either decarburize or combine with iron to form FeO. This means that more Fe_3O_4 must be provided than is needed for the carbon, the amount of the excess depending on a variety of rate factors. The presence of this alternative reaction is a complication, but does not alter the ultimate carbon equilibrium that is possible with sufficient Fe_3O_4.

Equilibrium is represented by the intersection of the carbon potential (slope = 1/2) and oxygen potential (slope = 1) lines on a $CO + CO_2$ diagram. If these intersect at $CO + CO_2$ pressure greater than 1 atm, the generated gas can blow off continuously. If they intersect at a pressure less than 1 atm, this lower pressure will be reached and reaction will stop. If the iron–iron-carbide line stops before reaching the relevant oxide line it should be produced to intersect, and treated as if it did continue. This line represents the carbon potential of the available carbon, a value to which the atmosphere in contact will also tend, even if it is simultaneously oxidizing to the metallic iron. Rate factors may favour the oxidation of iron and prevent a complete establishment of carbon equilibrium or vice versa.

Limitations to the Use of the Diagrams

Uncertainties in the basic data and the straight-line assumptions in the free-energy equations should only cause minor discrepancies. However, care is needed to be certain what the conditions of exposure are. A fairly exact knowledge of temperature is necessary since the gas may change rapidly with temperature for given solid components.

Where the gas is freely exposed to the surface o the solids, it is unlikely that equilibrium will be reached without recirculation. The faster the flow through, the further from equilibrium for the gas, although the solids, if limited in amount, will move towards equilibrium with the incoming gas.

If the amount of gas is small compared with the solid phases or the access is bad (as between the sheets in a stack) then the gas will come to equilibrium with the solids present between the sheets. On the other hand, the extreme edge of the stack will come to equilibrium with the recirculating gases. The diagrams can be used to indicate what solids will form on the edges of a stack from the flow past of a given gas, or alternatively, to predict from a knowledge of the components present on the sheet surfaces what the composition of the gas will be between the sheets. In general, the two gas compositions will be different. Between the two will be a transition zone, controlled partly by diffusion and partly by any edge oxide or carbide that may have formed earlier. Even along this gradient a close approach to equilibrium is likely from point to point, between the local gas composition and the local solid phases.

Commercially used atmospheres carry H_2, H_2O, and CH_4 as well as CO and CO_2. Provided the solid phases present at equilibrium are known, the CO and CO_2 values are still those given on the diagrams; the other gases must adapt themselves to the oxygen and carbon potentials already determined. If the mixed atmosphere is present in excess, it may be necessary to take the other gas reactions into account, particularly on a laboratory scale. On a production scale, ferrite saturated with carbon is usually an invariable end component. As the temperature drops below 600°C the equilibrium total of CO and CO_2 for carbon-saturated ferrite drops so sharply that the further decrease due to the reaction between CO and H_2 to form CH_4 is comparatively unimportant. Other reactions involving H_2 and H_2O are also probably not important in determining the ultimate equilibrium, though they may hasten the approach to it.

Despite these limitations, it seems that there is usually a way in which the diagrams can be applied to give specific information, even if the conditions have to be analysed carefully, and different answers found for different parts of the system. The figures present the thermodynamic data in a readily usable form which allows oxygen and carbon potentials to be considered simultaneously.

APPENDIX

Calculation of the Equilibria

For calculating equilibria it is necessary to choose and adhere to a consistent set of basic data. For simplicity, linear equations have been used throughout for free energies. For oxides, the values have been taken from Bulletin 542 of the U.S. Bureau of Mines.[6] For carbides, the equations given by Richardson[1] have been used. The solubility of cementite in alpha iron is taken from Darken and Gurry[5] and the water-gas equilibrium constant from the data of Austin and Day.[7]

The fact that wüstite is not stoichiometric FeO has been recognized throughout, which leads to decimal coefficients in the equations. On the other hand, the higher carbide of iron has been taken as Fe_3C since the thermodynamic data are less firmly established. Although $Fe_{20}C_9$ would be more correct, it has been referred to here in its simpler form of Fe_3C and Richardson's data used.[1]

The following are the basic equations with the associated free energies and the quoted ranges of temperature over which they are applicable. By going to 750° C the expressions for Fe_3O_4, Fe_2O_3, and Fe_3C have been extended somewhat beyond the recommended range, but the deviations are not serious and have not warranted fuller calculations.

Basic Equations	ΔG	Range, °C
$0{\cdot}947\,Fe + \frac{1}{2}O_2 = Fe_{0{\cdot}947}O$	$-63200+15{\cdot}47T$	25–1377
$3Fe + 2O_2 = Fe_3O_4$	$-265660+76{\cdot}81T$	25–627
$2Fe + 3/2O_2 = Fe_2O_3$	$-195450+61{\cdot}38T$	25–677
$C + \frac{1}{2}O_2 = CO$	$-26760-20{\cdot}98T$	25–1727
$C + O_2 = CO_2$	$-94260-0{\cdot}27T$	25–1727
$3Fe + C = Fe_3C$	$+6380-5{\cdot}92T$	190–842
$2Fe + C = Fe_2C$	$+4930-2{\cdot}60T$	25–527
log %C (cementite in alpha)	$-9700/4{\cdot}575T + 0{\cdot}41$	

All the remaining equations have been derived from those above by elimination of unwanted components and incorporation of CO and CO_2.

In all the equations the factors are chosen so that the coefficient of CO_2 in the final equation is unity. This is for convenience and uniformity but the choice is arbitrary. Equations are also written so that CO_2 appears on the left-hand side.

For example, to form Fe_3C from Fe_3O_4 by $CO + CO_2$ the following partial equations are needed:

	Factor	ΔG
(*a*) $6/11\,Fe + 4/11\,O_2 = 2/11\,Fe_3O_4$	2/11	$-48302+13{\cdot}96T$
(*b*) $14/11\,C + 7/11\,O_2 = 14/11\,CO$	14/11	$-34058-26{\cdot}70T$
(*c*) $6/11\,Fe + 2/11\,C = 3/11\,Fe_3C$	3/11	$+1345-0{\cdot}71T$
(*d*) $C + O_2 = CO_2$	1	$-94260-0{\cdot}27T$

Both the terms of the equations and the free energies have been multiplied by the factors shown; (*a*) and (*b*) should be added and (*c*) and (*d*) subtracted. This gives

$$3/11\,Fe_3C + CO_2 = 2/11\,Fe_3O_4 + 14/11\,CO$$
$$\Delta G = +10555-11{\cdot}76T$$

For this equation the equilibrium constant is given by:

$$\log K = 14/11 \log p_{CO} - \log p_{CO_2} = \frac{-\Delta G}{4{\cdot}575T} = -\frac{2307}{T} + 2{\cdot}570$$

All other derived equations have been formed in the same way from the basic values.

Derived Equations in terms of $CO + CO_2$

(1) $CO_2 + C_{gr} = 2CO$ $+40740-41{\cdot}69T$
$\log (CO^2/CO_2) = -8905/T + 9{\cdot}113$

(2) $0{\cdot}947Fe + CO_2 = Fe_{0{\cdot}947}O + CO$ $+4300-5{\cdot}24T$
$\log (CO/CO_2) = -940/T + 1{\cdot}145$

(3) $3/4Fe + CO_2 = 1/4Fe_3O_4 + CO$ $+1085-1{\cdot}51T$
$\log (CO/CO_2) = -237{\cdot}1/T + 0{\cdot}330$

(4) $2/3Fe + CO_2 = 1/3\,Fe_2O_3 + CO$ $+2350-0{\cdot}25T$
$\log (CO/CO_2) = -513/T + 0{\cdot}055$

(5) $Fe_3C + CO_2 = 3Fe + 2CO$ $+34360-35{\cdot}77T$
$\log (CO^2/CO_2) = -7510/T + 7{\cdot}819$

(6) $Fe_2C + CO_2 = 2Fe + 2CO$ $+35810-39{\cdot}09T$
$\log (CO^2/CO_2) = -7819/T + 8{\cdot}544$

(7) $3{\cdot}807Fe_{0{\cdot}947}O + CO_2 = 1{\cdot}202\,Fe_3O_4 + CO$ $-11162+12{\cdot}70T$
$\log (CO/CO_2) = +2440/T - 2{\cdot}776$

(8) $2Fe_3O_4 + CO_2 = 3Fe_2O_3 + CO$ $+12470+9{\cdot}81T$
$\log (CO/CO_2) = -2726/T - 2{\cdot}144$

(9) $2{\cdot}379Fe_{0{\cdot}947}O + CO_2 = 1{\cdot}126\,Fe_2O_3 + CO$ $-2287+11{\cdot}62T$
$\log (CO/CO_2) = +499{\cdot}8/T - 2{\cdot}540$

(10) $0{\cdot}2399Fe_3C + CO_2 = 0{\cdot}760Fe_{0{\cdot}947}O + 1{\cdot}240\,CO$ $+11510-12{\cdot}56T$
$\log (CO^{1{\cdot}24}/CO_2) = -2516/T + 2{\cdot}745$

(11) $1/5Fe_3C + CO_2 = 1/5Fe_3O_4 + 6/5\,CO$ $+7740-8{\cdot}36T$
$\log (CO^{1{\cdot}20}/CO_2) = -1692/T + 1{\cdot}827$

(12) $2/11\ Fe_2C + CO_2 = 3/11\ Fe_2O_3 + 13/11\ CO$ $+ 8170 - 6{\cdot}71T$

$\log (CO^{1\cdot182}/CO_2) = -1786/T + 1{\cdot}467$

(13) $3\ Fe_2C + CO_2 = 2Fe_3C + 2CO$ $+ 38710 - 45{\cdot}73T$

$\log (CO^2/CO_2) = -8461/T + 9{\cdot}996$

(14) $3/11Fe_2C + CO_2 = 2/11Fe_3O_4 + 14/11\ CO$ $+ 10555 - 11{\cdot}76T$

$\log (CO^{1\cdot272}/CO_2) = -2307/T + 2{\cdot}570$

Inspection of the diagram shows that a 50°C step makes a considerable difference in the position of most of the boundary lines. This means that the errors due to the straight line approximations are quite small, particularly if expressed in terms of temperature differences. The greater accuracy given by expressions with non-linear terms is not justified, nor are the slight errors involved in going up to 750°C of any consequence. However, if any temperatures above this are considered, the linear equations for $Fe_3O_4 + Fe_2O_3$ for the higher temperature range should be used in place of these given here.

Acknowledgments

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Letter to the Editor

Impact Properties of High-purity Nickel–Chromium–Molybdenum Steels

FOR MANY LOW-ALLOY STEELS, in the hardened-and-tempered condition, the relationship between room-temperature impact strength and tempering temperature shows a minimum after tempering at 250–400° C. This effect, sometimes called 'Izod-trough' or '350° C embrittlement', is associated with a maximum impact-transition temperature for material tempered in that range. The occurence of 'Izod-trough' embrittlement often presents a problem in the application of high-tensile steels because it limits the choice of tempering temperature.

High-purity nickel–chromium steels have been shown to be immune from another form of embrittlement, namely that resulting from prolonged re-heating at about 450° C after tempering at higher temperatures.* It therefore appeared pertinent to investigate the behaviour of 'pure' steels tempered in the 'Izod-trough' embrittlement range.

Two nickel–chromium–molybdenum steels having, respectively, nominal carbon contents of 0·3% and 0·4% were prepared from high-purity materials melted and cast *in vacuo* to give 22-lb ingots. The analyses of the steels are given in Table I. The steels were forged and hot-rolled to ¾-in. dia. bar. Blanks for provision of standard Charpy V-notch impact test-pieces were heat-treated by oil-quenching after 1 h at 850° C, followed by tempering for ½ h at temperatures in the range 150–550° C (in steps of 50°), and water-quenching. Impact values for specimens treated at each tempering temperature were determined in duplicate, at 20° and at − 78° C.

The hardness values of the steels after tempering,

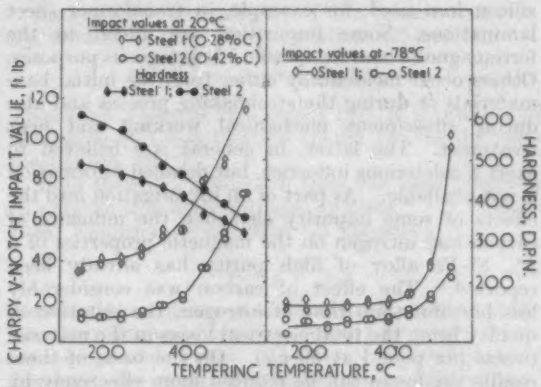

Fig. 1—Hardness and impact values of quenched and tempered high-purity 1¼%Ni–Cr–Mo steels

and the curves relating impact values with tempering temperature (for tests both at room temperature and at − 78° C) are given in Fig. 1. The data show that neither of the steels exhibited an 'Izod-trough'. It is of interest to note also that the room-temperature impact values of steel 1 (0·28% C) remain at a high level (> 35 ft-lb) for all tempering temperatures.

In contrast to the observed influence of purity on impact behaviour, the relationships between tempering temperature and the tensile properties of the high-purity steels did not differ significantly from those obtained with steels of commercial purity.

The results show that in steels of controlled purity it is possible to eliminate 'Izod-trough' embrittlement, and future investigations on the causes and mechanism of this type of embrittlement should take these findings into account.

The writers wish to thank The Mond Nickel Company, Ltd., for permission to publish this letter.

J. M. CAPUS
G. MAYER

The Mond Nickel Company, Ltd.,
Development and Research Department,
Wiggin Street,
Birmingham 16.

11th April, 1958

*K. Balajiva, R. M. Cook, and D. K. Worn, *Nature*, 1956, vol. 178, p.433.

TABLE I

Analyses of High-Purity Steels

Steel	Composition, wt-%							
	C	Si	Mn	Ni	Cr	Mo	S	P
1	0·28	0·05	<0·02	1·40	1·10	0·23	0·003	0·005
2	0·42	0·04	<0·02	1·53	1·09	0·24	0·003	0·006

Solubility and Diffusion of Carbon in a Silicon–Iron Alloy

By D. A. Leak, B.Sc., and G. M. Leak, B.Sc., Ph.D.

SYNOPSIS

There is a need for data on the solubility and diffusion rate of carbon in silicon–iron transformer sheet. Internal friction measurements have been made to study this problem. Three relaxation peaks have been observed. Volume diffusion occurs by the same interstitial mechanism as is observed in α-iron containing carbon. Carbon atoms in solution also are associated with silicon atoms in a similar way to earlier observations on nitrogen in silicon iron. This association is less marked in the specimens containing carbon. The solubility of carbon, in equilibrium with a precipitated carbide, is considerably lower than that for carbon in α-iron; for example, at 700° C the solubilities are about 0·005 wt-% in iron containing 3% Si and 0.02 wt-% in α-iron. The carbide in the silicon iron appears to be cementite, Fe_3C.

1539

INTRODUCTION

IMPURITIES influence the magnetic properties of silicon iron used, for example, in transformer sheet laminations. Some impurities, are added to the ferromagnetic base for specific advantageous purposes. Others occur incidentally either from the initial base materials or during the steelmaking process and also during subsequent mechanical working and heat treatment. The latter, in general, are believed to exert a deleterious influence, but detailed information is not available. As part of an investigation into the effects of some impurity elements, the influence of carbon and nitrogen on the magnetic properties of a 3% Si–Fe alloy of high purity has already been reported.[1] The effect of carbon was considerably less harmful than that of nitrogen, the criterion of quality being the total electrical losses in the material (watts per pound at 50 c/s). On the basis of these results the losses can be reduced more effectively by reducing the nitrogen content of the material; but it would still be possible to improve losses by reducing the carbon content below the level usually found in commercial alloys. As an alternative to removing the carbon it might be possible to precipitate it in such a form that it exerts a less adverse effect than that of the carbide originally present in the material. The facility with which either of these two possibilities might be carried out depends to some extent upon a knowledge of the solubility and diffusion rate of carbon in these alloys. Interpretation of the magnetic measurements also requires knowledge of these factors to estimate the form of precipitation of the carbide which causes the deleterious magnetic properties.

Commercial heat-treatment of silicon irons is partially designed to reduce (or not increase) the carbon content and also to eliminate subsequent ageing. This ageing might be due to carbon or nitrogen and adequate control of it requires a knowledge of the factors influencing precipitation of carbides in the alloys. This becomes more essential when it is realized that the simultaneous presence of nitrogen and carbon might give rise to accelerated ageing in the same way as has already been reported for Fe–C–N alloys.[2]

Published data on the effect of silicon on the solubility of carbon in α-iron is scarce. Smith's measurements[3] suggest that the solubility should not be very different from that in pure iron, whilst Gardner[4] suggests that the carbon solubility is much less than that in pure iron at temperatures below 600° C. By comparison with data for nitrogen in silicon iron[5] it would be expected that the solubility of carbon would be less than in α-iron but that its diffusion rate would be unchanged by the silicon content.

The present report is based on internal friction measurements. A number of investigations have been reported concerning the contribution to internal friction (damping) of an interstitial solute in a pure (body-centred cubic) metal. The mechanism giving rise to the damping is well understood. Very little work has been reported for more complex systems, in particular for an interstitial solute in an alloy. As an example of this, Fast and Meijering[6] investigated Fe–V–N specimens and found that whilst the original Snoek-type peak was still observed at about 20° C (frequency of vibration 1 c/s), a second peak was

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The authors are at the Sheffield laboratories of B.I.S.R.A.

observed at a much higher temperature ~90° C. This higher temperature peak was assumed to be due to absorption of energy by nitrogen atoms moving in abnormal interstices associated with precipitated particles of vanadium nitride. Similar work on iron–manganese–nitrogen[23] gave a broadened low-temperature peak instead of two clearly resolved peaks. The broadening was assumed to be due to the superposition of two relaxation peaks. This type of investigation was carried a stage further for the Fe–Si–N system,[5] in which the two, or perhaps three, relaxation peaks were assumed to correspond to movements of nitrogen atoms in different interstices in the b.c.c. silicon-iron lattice.

The lower temperature peak corresponded to the one observed in pure α-iron–nitrogen alloys whilst the second was presumed to be due to jumps of nitrogen atoms between interstices where one of the nearest solvent atoms was a silicon atom. The majority of the nitrogen atoms preferred these latter sites. Some indication was found that a third relaxation might be observed, although its reproducibility was poor. The solubility represented by its peak height was very low and would not significantly affect the final results and so it was omitted from the measurements. However, Rawlings and Robinson[12] have recently carried out similar measurements on alloys of nitrogen in iron containing about 1% Si and have observed three and perhaps four peaks. Their results also show that the contribution of two of these peaks to the measured solubility is very slight. There has been some criticism of internal friction work, primarily on the grounds that the results differ from more orthodox chemical measurements. These differences will presumably be resolved when further work on these systems has been carried out.

The paper presents the results of an investigation of both the solubility and diffusion rate of carbon in a 3% Si–Fe alloy of high purity. The solubility considered here is that for equilibrium between carbon in solution and carbon as a precipitated carbide.

TECHNIQUE

The internal friction technique has been described in some detail elsewhere.[6, 7] The essential points are given below with particular reference to the present problem.

Specimens about 250 mm × 1 mm × 0·3 mm were cut from material processed to yield strip for orthodox magnetic hysteresis measurements. A specimen forms the suspension of a system freely oscillating at frequency ω. Internal friction is then observed as the logarithmic decrement δ for the resulting decay of free vibrations. Where the mechanism giving rise to the internal friction can be described by a single relaxation time τ, where τ is dependent upon temperature T through an activation energy Q, according to

$$\tau = \tau_0 \exp \frac{Q}{RT} \quad \ldots\ldots (1)$$

then the internal friction δ is given by

$$\frac{\delta}{\pi} = \Delta \frac{\omega\tau}{1 + \omega^2\tau^2} \quad \ldots\ldots (2)$$

Δ is the relaxation strength of the mechanism giving rise to the internal friction, which here is that of stress-induced ordering of interstitially dissolved carbon atoms in the b.c.c. iron lattice. These carbon atoms introduce tetragonal distortion which under the action of an oscillating stress system tends to become aligned in such a way that the resultant total distortion is minimized. Δ is directly proportional to the amount of carbon atoms taking part in this mechanism, and τ, related to the time taken for a carbon atom to jump from one interstitial site to a neighbouring site, is also related[8] to the diffusion rate D for the solute atom by

$$D = \frac{a^2}{36\tau} \quad \ldots\ldots (3)$$

Here, a is the lattice parameter for the b.c.c. lattice. The variation of D with temperature is given by

$$D = D_0 \exp(-Q/RT) \quad \ldots\ldots (4)$$

where D_0 is a constant independent of temperature.

From equation (2), the internal friction is a maximum when $\omega\tau$ is equal to unity and then the peak height in a plot of δ versus T is given by

$$\frac{\delta}{\pi} = \frac{\Delta}{2} \quad \ldots\ldots (5)$$

Thus the relaxation strength Δ, and so the amount of dissolved solute, can be determined.

Also, at the temperature of the peak maximum, T_p, since $\omega\tau$ is unity, from equations (3) and (4),

$$D = \frac{a^2\omega}{36} = D_0 \exp(-Q/RT_p) \quad \ldots\ldots (6)$$

Thus from a plot of $\ln\omega$ versus $1/T_p$ it is possible to determine Q, the activation energy for the diffusion mechanism, and D_0.

More than one relaxation time has been observed in work on iron-alloy–nitrogen systems.[5, 9, 10] Under these conditions,[11] equation (2) becomes

$$\frac{\delta}{\pi} = \Sigma_1 \Delta_1 \frac{\omega\tau_1}{1 + \omega^2\tau_1^2} \quad \ldots\ldots (7)$$

Provided the number of mechanisms is small then the resultant internal friction curve can be resolved into its component peaks. The total solubility then becomes the sum of the separate 'solubilities' measured by each of the component relaxation peaks. A separate jump rate or diffusion rate can be calculated for each relaxation mechanism.

The results reported below show that the Fe–Si–C system gives rise to two relaxation peaks, with a possibility of a third.

This latter peak, at the highest temperature, was not observed in every experiment. Accurate values of Q and T_p for each peak can be determined from measured curves taken at frequencies such that component curves can be resolved.

SPECIMEN PREPARATION

Specimens were cut from high-purity materials which had been melted and cast in vacuum. The ingot analysis in wt-% was:

Si	C	N	S	P	Al	O
2·83	0·023	0·004	0·008	0·012	0·002	0·0038

After forging, the material was hot-rolled, and then cold-rolled in two stages with an intermediate anneal at 850° C. The strip was then 0·3 mm thick and 4 cm wide. Annealing was carried out under flowing hydrogen which tended to remove carbon, nitrogen, and sulphur. Carbon and nitrogen were removed

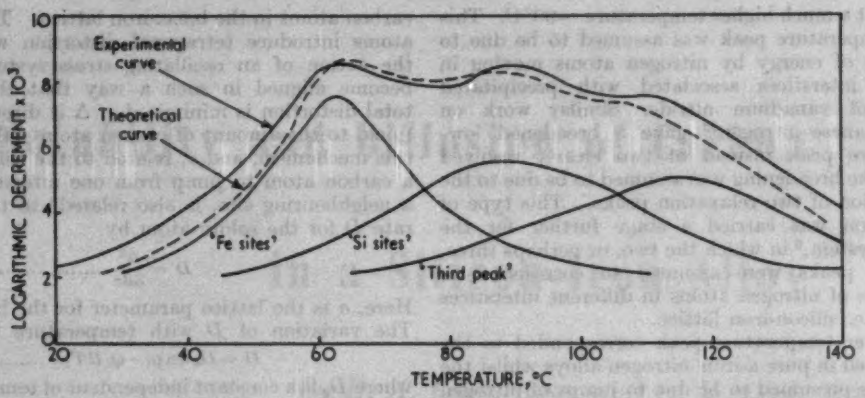

Fig. 1—Typical curve of logarithmic decrement versus temperature. Specimen quenched from 800° C. Frequency of oscillation 7·125 c/s

from the final specimens by annealing at 1000° C in an atmosphere of flowing dry hydrogen. The carbon and nitrogen contents then were less than 0·0005 wt-% by both chemical analysis and internal friction measurements.

Two methods were used to introduce carbon. In the first, specimens were coiled and held in a furnace at about 700° C under an atmosphere of flowing dry hydrogen. Heptane was introduced into the system for the appropriate time (10–60 min) to give a range of carbon contents. The specimens were then homogenized at 1000° C for 17 h. Analyses showed that the specimens were reasonably homogeneous, i.e. the carbon content did not vary significantly along the length of the specimens.

The second method was to equilibrate the specimens, free carbon, and a CO_2–CO atmosphere in a closed system at 1000° C. By limiting the amount of carbon available, a range of carbon contents could be attained.

In these ways specimens were produced containing carbon at levels between 0·0005 and 0·15 wt-%.

Preparatory to internal friction measurement, specimens were sealed in vacuum (1–5 μ Hg) in hard glass or silica, heated to the appropriate carbon solution temperature, and quenched into water at room temperature. The glass sheaths broke automatically; the silica sheaths had to be broken mechanically. Both methods gave a very fast quench. Chemical analysis showed that carbon was not lost from the specimens by this treatment.

For the determinations of the diffusion rate, specimens containing 0·02 or 0·03 wt-% C were quenched from temperatures between 800° C and 900° C. Immediately after quenching, the temperature of the internal friction peak was determined for various frequencies of oscillation.

For the determination of solubility the following procedure was used. A preliminary survey of the variation of solubility with temperature was made from which it was possible to select a specimen which contained somewhat more carbon than would be in solution at the temperature to be investigated. This specimen was then quenched from that temperature and the peak height determined immediately. Subsidiary experiments were carried out to show that the measured peak height was not influenced significantly by ageing.

No variation in measured peak height was observed after holding the specimen at the quenching temperature for times ranging from 1 to 16 h (at a temperature of 800° C). Subsequently a standard time of 1 h for soaking at temperature was used.

The resulting measure of solubility was a sum of the peak heights in units of logarithmic decrement. The proportionality constant was determined using specimens containing an amount of carbon that was observed experimentally to be fully in solution at the quenching temperature. Chemical analysis then gave the proportionality directly.

DETERMINATION OF DIFFUSION RATE

As had been anticipated from the previous work on Fe–Si–N specimens,[5] two peaks were observed with certainty and a third peak had to be inferred for the analysis of some of the curves (Fig. 1). This third peak was not observed with the same reproducibility as the two major peaks. In the present case the

Table I

VARIATION OF PEAK TEMPERATURES WITH FREQUENCY OF VIBRATION

Frequency of Oscillation, s^{-1}	Temperature of Peaks, °C			Diffusion Rate, $\times 10^{10}$ cm^2. s^{-1}
	'Fe Sites'	'Si Sites'	'Third Sites'	
13	62	100	...	18·57
9·25	70	96	...	13·81
7·4	64	94	120	11·5
7·125	62	88·5	112	10·18
6·75	57	85	...	9·64
3·84	54	77	95	5·48
2·32	48·5	69	...	3·313
2·13	50	68	...	3·04
1·8	45	65	81	2·57
1·78	44·5	69	90	2·54
1·25	42	63	85	1·785
0·89	38	52·5	72·5	1·265
0·65	35	49	70	0·928
0·625	32	46·5	...	0·892
0·58	33·5	53	...	0·832
0·52	35	48	...	0·738
0·51	26	45	60	0·728
0·32	26	36	48	0·456

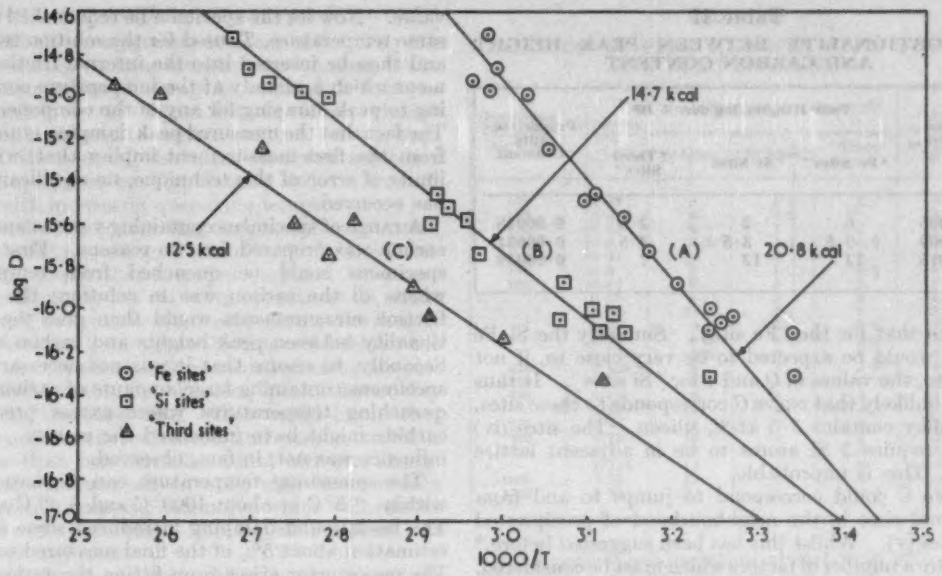

Fig. 2—Diffusion rate for carbon in silicon iron plotted as log D versus $1000/T$. Curves A, B, and C correspond to the three resolved relaxation peaks

lowest temperature peak was at the same temperature as for an experiment at the same frequency carried out on a specimen of pure α-iron containing carbon.

The results are given in Table I and in accordance with equation (6) are plotted in Fig. 2 in the form of log D versus $1000/T$. The designation of these peaks as due to ' Fe sites ', ' Si sites ', and ' third sites ' will be discussed below. The lattice parameter a has been taken to be $2{\cdot}857 \times 10^{-8}$ cm.[13] The curves for each of the series of results for the three peaks follow straight lines. The lowest temperature peak corresponding to the pure Fe–C peaks gives an activation energy Q equal to 20·8 kcal/mole, curve A; the value for pure Fe–C is 20·4.[14] The next peak, curve B, gives Q equal to 14·7 kcal/mole, and the third peak, curve C, Q equal to 12·5 kcal/mole. The corresponding values for D_0 (equation 4) are 0·03, 10^{-6}, and 10^{-8} cm^2. s^{-1} respectively.

INTERPRETATION OF DIFFUSION-RATE MEASUREMENTS

The existence of these internal friction peaks can be explained by the jumping of interstitially dissolved solute atoms into neighbouring sites which are preferred under the action of the stressing system imposed by the experiment. The possible jumps which might be made are then:

(i) To and from sites where the solute atom has Fe atoms as nearest neighbours. This corresponds to the pure iron–carbon case. Such jumps give rise to the lowest temperature peak and are called here Fe-site jumps (in agreement with the Fe–Si–N work[5])

(ii) To and from sites with one Si atom as one of the nearest neighbours: called Si-site jumps

(iii) From a site with all Fe nearest neighbours to one with an Si atom as a nearest neighbour ($\overrightarrow{\text{Fe–Si}}$ site jumps) or vice versa ($\overrightarrow{\text{Si–Fe}}$ site jumps)*

(iv) To and from sites with two Si atoms as nearest neighbours

(v) To and from abnormal sites in the neighbourhood of precipitated particles of a second phase (carbide).

In view of the agreement with the Fe–C system it is obviously reasonable to assume that curve A corresponds to the jumps of type (i), i.e. ' Fe sites'. Dissolved carbon atoms expand the lattice, or at least push apart the two nearest neighbouring atoms in the same way as does nitrogen.[15] Silicon atoms cause a contraction of the lattice.[13] As a result, the combination of a carbon atom with a silicon atom as one of its nearest neighbours presents less resultant distortion to the surrounding lattice than would the two separated atoms. There is thus a tendency for carbon atoms to remain associated with silicon atoms. It is also reasonable to assume that the activation energy corresponding to jumps to and from these sites will be lower than for the ' Fe sites '. It is assumed that curve B corresponds to these ' Si sites '. The contribution to bulk diffusion due to these sites is small.

It is not easy to define the mechanism giving rise to curve C. The Fe–Si and Si–Fe sites may be considered in the following way. An Fe–Si jump would have an activation energy and relaxation time (and hence peak temperature) similar to that for an Fe-site jump. If there is any significant change in the activation energy it would be expected to be very

* The notation indicates that a carbon atom jumps in the direction of the arrow. It is probable that the energy required to jump from an Fe site to an Si site, i.e. an $\overrightarrow{\text{Fe–Si}}$ jump, will be different from a jump in the reverse direction, i.e. an $\overrightarrow{\text{Si–Fe}}$ jump.

Table II
PROPORTIONALITY BETWEEN PEAK HEIGHT AND CARBON CONTENT

Carbon Content, wt-%	Peak Heights, log dec. × 10^3			Proportionality Constant
	'Fe Sites'	'Si Sites'	'Third Sites'	
0·005	6	2	2·5	0·00048
0·009	9·5	3·5	4·5	0·00051
0·015	12	12	7	0·00049

close to that for the 'Fe sites'. Similarly the Si–Fe jumps would be expected to be very close to, if not equal to, the values of Q and τ for 'Si sites'. It thus seems unlikely that curve C corresponds to these sites. This alloy contains 5·5 at-% silicon. The sites (iv) would require 3 Si atoms to be in adjacent lattice steps. This is improbable.

Curve C could correspond to jumps to and from abnormal sites in the neighbourhood of precipitated particles (v). Whilst this has been suggested before,[9] there are a number of factors which must be considered. The existence of a reasonably well defined peak automatically requires that the abnormal sites occupied by the carbon atoms in the vicinity of the precipitated particles must be such that a large proportion of them are identical. This is necessary to give a unique value for Q and τ. (The half-peak width for curve C corresponds to a value for Q equal to 12·5 kcal/mole and thus to a unique value for τ.) The magnitude of the peak should vary with the amount of precipitated phase; this phase must be the carbide.

DETERMINATION OF SOLUBILITY OF CARBON

Experimentally the internal friction curve is measured immediately after quenching a specimen from the temperature at which the solubility is to be measured. The sum of the peak heights, which combine to give the observed curve, is then proportional to the amount of carbon which was in solution at the quenching temperature. Two assumptions are involved in this procedure:

(i) That all the carbon in solution at the quenching temperature T remains in supersaturated solution after the quench into water at room temperature.

(ii) That ageing and precipitation of a carbide does not occur during the internal friction measurement.

The first assumption has been shown to be sensibly true in other systems; for example there is agreement between internal friction and orthodox chemical measurements in the iron–nitrogen system.[16] A second justification is that the proportionality between peak height and carbon (or nitrogen) content does not vary significantly with the quenching temperature for specimens in which all the carbon (or nitrogen) is in solution at the quenching temperature.

The second assumption can be shown to be sensibly valid in the following way. Let the internal friction curve be measured in the usual way up to the temperature at which the third peak would have its maximum value. Now let the specimen be requenched from the same temperature, T, used for the solution treatment, and then be inserted into the internal friction equipment which is already at the temperature corresponding to peak damping for any of the component peaks. The fact that the measured peak damping is unchanged from the first measurement implies that, within the limits of error of this technique, no significant ageing has occurred.

A range of specimens containing various amounts of carbon was prepared for two reasons. First, so that specimens could be quenched from temperatures where all the carbon was in solution: the internal friction measurements would then give the proportionality between peak heights and carbon contents. Secondly, to ensure that it was not necessary to use specimens containing large amounts of carbon for low quenching temperatures where excess precipitated carbide might have influenced the results. Such an influence was not, in fact, observed.

The quenching temperature can be measured to within $\pm$ 5° C at about 1000° C and $\pm$ 2° C at 400° C. The background damping introduced some error, by estimation about 5% of the final measured solubility. The major error arises from fitting theoretical curves to the observed experimental curve. This probably raises the total error in a solubility measurement to about $\pm$ 5%. Typical proportionality measurements are given in Table II. The carbon content was determined chemically. A number of damping determinations were made at each level of carbon content. The more accurate results are obtained at the higher carbon content so that more weight should be placed on the determination at 0·015% carbon. It is reasonable to assume a proportionality such that 1 unit of logarithmic decrement ($\times 10^{-3}$) is equivalent to 0·0005 wt-% carbon. The error in this is probably less than $\pm$ 5%.

This value for proportionality is significantly different from known values for the binary Fe–C system. The present results have been obtained using thin strips cut from rolled strip which possesses a texture which can roughly be described as $(1\bar{1}2)[110]$. This is considerably different from the texture of drawn wire, even after annealing treatments, and probably accounts for the differences in proportionality. This aspect is being studied further.

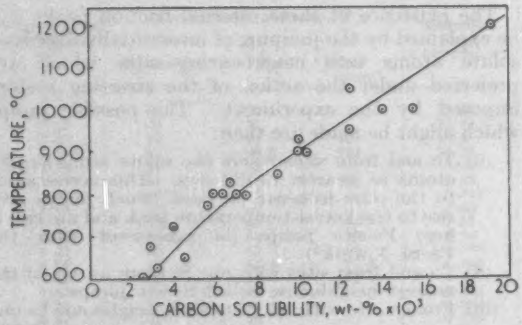

Fig. 3—Solubility of carbon in silicon iron in equilibrium with a precipitated carbide

DISCUSSION ON SOLUBILITY MEASUREMENTS

Table III shows a gradual increase in all the peak heights as the quenching temperature is raised. The scatter observed in the way in which this increase occurs is primarily due to the fact that interpretation of the graphs cannot be carried out in a unique way. However, the plot of the total observed solubility versus temperature in Fig. 3 does show a smooth increase with increasing quenching temperature.

It is worthwhile contrasting the present results with those obtained for nitrogen solubility.[5] In the latter case it was found that nitrogen occupied 'Si sites' almost exclusively up to a temperature of about 1000° C and that above this temperature the height of the 'Fe sites' peak gradually increased whilst the height of the 'Si sites' peak remained almost constant. In the present results the 'Fe sites' peak is invariably bigger than the other two. This would imply that the interaction between silicon and carbon atoms is much less than between silicon and nitrogen atoms. This point can be resolved only with the use of a high-frequency damping technique which will resolve the peaks more accurately. This work is in hand and will be reported later.

A second significant point refers to the magnitude of the third peak. Most of the experiments were carried out with specimens containing 0·018 or 0·028 wt-% carbon. However, a few were repeated using material with carbon contents up to 0·15 wt-%. In no case was there a significant increase in the height of the third peak. It was suggested earlier that such an increase might be observed. Again it is possible that a slight variation of peak height would be observed by using a more refined technique to resolve the peaks. However, a third peak was observed with specimens quenched from temperatures where all the carbon was in solution. Thus it would appear that the third peak must correspond to $\overrightarrow{\text{Fe–Si}}$ to $\overrightarrow{\text{Si–Fe}}$ jumps. This point will be investigated in more detail using higher-frequency damping methods.

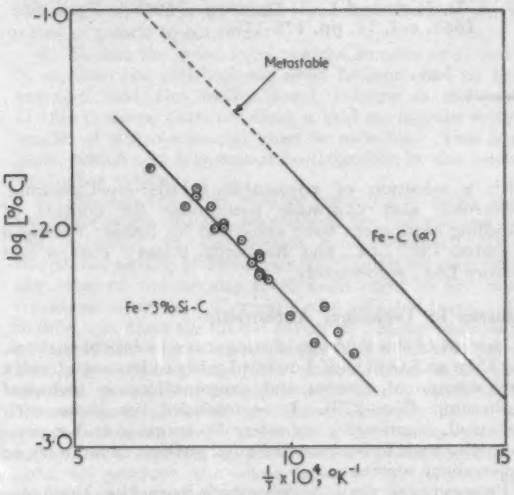

Fig. 4—Solubility measurements of Table III plotted in the form of log (concentration) versus 1000/T

Table III

VARIATION OF PEAK HEIGHTS WITH QUENCHING TEMPERATURES

Quenching Temperature, °C	Frequency, c/s	Peak Heights, log. dec. × 10²			Carbon Solubility, wt-% × 10²
		'Fe Sites'	'Si Sites'	'Third Sites'	
600	1·28	3	1·2	1	2·6
625	0·6	4	2·5	...	3·25
650	0·52	6	1	2	4·5
675	0·8	2·5	2·5	0·8	2·9
725	0·32	4	3	1	4
775	0·5	7	1	3·5	5·75
800	0·82	8	3	3	7
	0·89	6	3	3	6
	1·04	10	2	3	7·5
	1·25	7	3	2·5	6·25
	0·74	6·5	3·5	2·2	6·1
	7·125	5·5	4	3	6·25
825	0·625	8	3	2·5	6·75
850	0·65	8	6	4	9
900	0·75	8	8	4	10
	2·13	12	4	4·8	10·4
925	1·48	8	8	4	10
950	0·75	10	10	5	12·5
1000	7·4	12	12	7	15·5
	1·123	12	8	8	14
1050	1·78	12	5	8	12·5
1200	1·83	24	17	2·5	19·25

For a perfect solid solution of carbon in silicon iron the carbon solubility C wt-% in equilibrium with a precipitated carbide is given by:

$$\ln C = \frac{-\Delta H_1}{RT} + \text{constant} \quad \ldots\ldots\ldots\ldots\ldots (8)$$

Where ΔH_1 is the heat of solution per g-atom of carbon. Figure 4 shows a plot of log C versus $1/T$ for the results of Table III. The value for ΔH_1 lies between 8 and 10 kcal. Incidentally the linear relationship of Fig. 4 is evidence that the results are self-consistent. The accepted value for ΔH_1 in the system

$$Fe_3C \text{ (cementite)} \rightarrow 3 \text{ Fe } (\alpha) + C \text{ (in } \alpha) \quad \ldots\ldots\ldots (9)$$

gives ΔH_1 equal to 9·7 kcal per g-atom of carbon.[17] Consequently, although the present value for ΔH_1 may vary from this, the curve in Fig. 4 has been drawn with a slope corresponding to ΔH_1 equal to 9·7 kcal. The corresponding curve for the Fe–C (α) system has been included in Fig. 4, the values being taken from Wert.[18]

Darken and Gurry[17] also quote the following thermodynamic properties of carbon dissolved in iron:

$$C \text{ (graphite)} + 3 \text{ Fe} = Fe_3C \quad \Delta H_2 = 5{\cdot}1 \text{ kcal} \ldots (10)$$

Thus, summing equations (9) and (10),

C (graphite) = [C]α $\Delta H_2 = 14{\cdot}8$ kcal, which is the heat of solution of graphite in α-iron.

ΔH_1 is not markedly altered by the addition of 3% Si. It is reasonable that ΔH_2 is also not markedly affected. A similar observation was made by Turkdogan[19] for the Fe–Si–N system. There is not, as yet, an explanation for the differences in ΔH_2, given by Darken and Gurry[17] at 14·8 kcal and Smith[21] at 20 kcal. The explanation for this discrepancy might throw light on the differences in carbon solubilities in 3% Si iron shown by Smith[5] and the present work.

A possible source of difference might have been due to the nature of the carbide formed in the different experiments. Owen[20] showed that silicon did not enter the carbide phase in alloys containing up to

3·14% Si. This has also been verified in the present work; the carbide appears to be cementite Fe_3C. The X-ray measurements, confirming this point, have been made on carburized silicon–iron specimens and on carbides extracted chemically. This is consistent with the similarity between the heats of solution of the carbides in the 3% Si alloy and in pure α-iron; it does not account for the differences between these results and Smith's.[3]

The most significant point brought out by this work is the considerably reduced solubility of carbon in silicon iron (in equilibrium with a precipitated carbide), when compared with that in pure α-iron. At 700° C, for example, solubility in α-iron is 0·02% and in 3% Si iron it is 0·005 wt-%. The solubility measurements follow the equation

$$\log C = -\frac{2120}{T} - 0{\cdot}51.$$

The low solubility of carbon in this alloy, at temperatures about 800° C implies that very little magnetic ageing should be observed in specimens cooled quickly from this temperature. This has been observed experimentally.[22] This is especially significant in view of the relatively small effect of carbon on the magnetic properties of silicon iron, by comparison with the effect of nitrogen.[1] It is suggested that the major contribution to such ageing must be caused by precipitation of nitrogen as a nitride.

CONCLUSIONS

The bulk (volume) diffusion rate of carbon in iron containing 3% Si is virtually the same as that for carbon in pure α-iron. A significant proportion of the carbon atoms, interstitially dissolved, are associated with silicon atoms in the lattice.

The solubility of carbon, in equilibrium with a precipitated carbide, is considerably lower than the solubility in pure α-iron. This solubility is associated with a heat of solution similar to that for the carbide in pure α-iron, i.e. 9·7 kcal per g-atom of carbon. The precipitated carbide is cementite, Fe_3C.

Acknowledgments

Most of the experimental work was carried out by Mr. J. H. E. Fox, and the analysis through Mr. K. Speight. The authors appreciate the critical discussions with their colleagues, particularly Dr. E. T. Turkdogan who clarified the thermodynamic implications.

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International Mechanical Handling Exhibition

This exhibition, organized by the journal *Mechanical Handling*, took place at Earls Court from 7th to 17th May.

Noteworthy in a wide range of handling equipment were electric hoist blocks controlled by tape for automatic operation made by the Vaughan Crane Co., Ltd.; a 12,000-lb capacity fork-lift truck with combined steering and mast-slewing which, it is claimed, can negotiate quite narrow doorways, made by Ransome and Rapier Ltd., and the new "Flexiroll" conveyor system with new-type troughing and return-belt idlers made by Fisher and Ludlow Ltd.

The steel industry was represented by Guest Keen and Nettlefolds Ltd., with their selection of fastening devices; Accles and Pollock Ltd., with tubing designed for hydraulic and other applications; and Tubewrights Ltd., with a selection of adjustable tubular-steel racking. Electronic and hydraulic equipment for control of handling equipment were exhibited by British Thomson Houston Co., Ltd., and Keelavite Rotary Pumps and Motors Ltd., respectively.

Courses in Technical Authorship

In view of the shortage of competent technical authors, the City and Guilds of London Institute has organized a new scheme of courses and examinations in technical authorship (No. 229). It is intended for those with technical, engineering, or scientific training and experience who wish to become technical authors in industry or government service.

Prospectuses may be obtained from the Institute, Gresham College, Basinghall Street, London, E.C.2. price 9*d*. (including postage).

Correspondence on the Papers—

Heat Flow in Ingot Hot-tops* by G. Fenton,

and

Studies on Ingot Feeder Heads† by H. S. Marr, G. Fenton and W. H. Glaisher

Mr. **W. Ash** (Steel, Peech and Tozer): The authors have reviewed standard hot-topping practice in a very practical manner and have shown where inefficiencies occur. They have gone on to review the remedies and have not avoided mentioning the disadvantages of the new materials proposed. The benefits seem to be that top discards can be reduced to about 6% compared with current practice of 12–15%.

A good feature of exothermic hot-tops is their ability to float out segregated material into a horizontal layer at the top of the head, instead of the more usual inverted conical disposition. Their main drawback, however, seems to be that they can be used only once. This needs further thought, because it is common for hot-tops to be used a number of times before re-making, thus reducing cost and inconvenience very appreciably. Finally, in spite of the good performance of the exothermic hot-tops, the cost still remains uneconomical for bulk use with plain carbon steels.

Mr. **D. Campbell** (Brymbo Steel Works Ltd.): These two very commendable papers are of great interest to the majority of makers of killed steel. The increase of yield can be considerable, in both the use of insulating firebrick tiles and exothermic coated tiles.

However, the extra cost involved—costlier refractories (or coated tiles), increased labour costs, and the cost of top additions—would probably make the procedure an unattractive economic proposition in many works. It can be envisaged, though, that where highly alloyed steels are involved, then the procedure would probably be well worth while.

When the feeder head volume is reduced, there are a number of points to consider:

(i) Should the total ingot weight remain as it was? If so, then the chill volume must be increased by the amount that the feeder head volume is reduced. If this is done, then to effect a real saving the extra length of prime material must be saleable. This is a point which can sometimes be forgotten in the quest for higher yields.

(ii) Should the chill volume remain the same and the total ingot weight be reduced by the amount of the reduction in the feeder head volume? Here the actual saving of metal per ingot must be such that the total of the savings from each ingot in the cast equals at least the full weight of a saleable ingot. If it does not, then the metal saving is not economically effective; if it exceeds the weight of one saleable ingot but is less than that of two ingots, then again the greatest possible economic benefit is not realized.

These points must be considered carefully when an improved hot-topping procedure is contemplated. Another consideration is that rolling a smaller ingot weight to produce the same saleable weight should result in some saving on the mill side.

Exothermic compounds contain a certain amount of aluminium, and steel in contact with them will pick it up. Have the authors measured this pick-up, and how far into the ingot it extends? Assuming that pick-up does occur, the use of these compounds is not permissible in the production of steels which must be free from aluminium. It is well known that an addition of aluminium to steel can produce fine-grained steel. This being so, it might be that steel leaving the ladle as inherently coarse-grained will pick up aluminium from the exothermic compound and finally exhibit either a duplex or a fine grain size.

It is generally held that the feeder head is useful because products of flotation from the ingot body rise into that part, which is eventually scrapped. Assuming that this viewpoint is valid (at least in all but rather small ingots) it would be interesting to know what effect the smaller, more efficient hot-top has on the non-metallic inclusion content of the steel in that part of the ingot which becomes saleable.

Finally, referring to the B.I.S.R.A. 'double headbox,' have the authors considered flame-sprayed cermet coatings, which can be applied very thinly? I have in mind the extremely good adhesion of alumina flame-sprayed on metal, and its very high melting point. The initial cost is high, and the deciding factor would be the number of heats which it would stand, which can be found only by trial.

Mr. **G. N. Cherry** (Foundry Services Ltd.): I feel there are points in the papers which might be usefully enlarged upon, particularly with regard to the shape of the feeder head, the top surface addition, and the backing in the duplex exothermic tile or sleeve.

A circular hot-top section will expose a smaller area of refractory per unit volume of steel than a square one. However, the use of exothermic circular sleeves has serious deficiencies owing to lapping over of the shoulder, as stated by the authors, and I would like to draw attention to the 'round-to-square' design of sleeve with which we have now had much experience. This sleeve is square at its base, developing to round at the top; it overcomes the problem of the ingot shoulder whilst reaching a compromise on section shape.

In the first paper, Mr. Fenton states that he would not expect even a mildly exothermic powder to give any significant improvement over vermiculite as a top addition. Here he is presumably referring to carbonaceous materials, and I would like his opinion on the contamination hazard.

Because of the emphasis of modern methods of heat-loss reduction being concentrated on improving heat transfer from the headbox walls, the heat lost from the top surface of the ingot is often insufficiently investigated. When exothermic additions are used, we should avoid the type which burns very quickly, for they are unsatisfactory on any ingot above, say, 6 in. section.

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* *J.I.S.I.*, 1957, vol. 186 pp. 396–405.

† *J.I.S.I.*, 1957, vol.187 pp. 81–92.

Invariably they have a high initial heat capacity before ignition, and can cause skulling which the exothermic powder, after ignition, can fail to remelt; it usually pays to use exothermic compounds which have a lower heat content before ignition (and usually a better insulating value) and which result in a truly flat feed with no top skull at all.

Cases are on record where changing over from a rapid-burning to a slow exothermic feeding compound has so reduced top skull on exothermically sleeved ingots that the additional metal available for feeding has enabled the head volume to be reduced by 1%. This 1% reduction is important economically, for if the head volume can be reduced from 8% to 7%, an economy of up to 12% on the cost of the exothermic sleeve or slab is obtained.

In Fig. 13 of the second paper, the authors have illustrated the advantages of exothermic top additions compared with no addition. It is apparent that the skull metal shown in Fig. 13*a*, has become available for feed metal in the heads shown in Figs. 13*b–c*. The slight tendency to top skulling in some of these heads would suggest that use had been made of an exothermic material with a high metallic content.

In dealing with exothermic tiles, the authors state that such tiles are in production use on ingots up to about 10 cwt, and so far only on alloy steels. This statement can now be modified as the 2-ton size in low-alloy steel is being cast, and a certain amount of pilot production of plain carbon steel up to 4 tons, but by far the biggest usage at the moment is on 1-ton alloy ingots.

The method of removing this last size from the ingot mould is worthy of mention since the exothermic composite unit is fully inserted into the ingot mould and no part of the solidified head projects above the mould. The hot-top is shaped to allow a secondary reservoir of molten metal to form between the hot-top and the mould wall, into which a lifting hook is dropped and by which the ingot is lifted from the mould. Other methods, such as formation of lugs in the small residual head by shaping the hot-top face, are also in regular use as a means of easy withdrawal of wide-end-up ingots from their moulds.

We would like to pay tribute to the work done by B.I.S.R.A. on composite tiles. We feel they have made an enormous contribution through their technical encouragement, which has influenced our own policy. As the authors have mentioned, efforts are being made to produce a cheap expendable tile in which the exothermic facing is backed with a good insulating material. Some measure of the success so far attained is given by the results of production tests on 50 ingots of alloy steel, where the use of this type of tile enabled a reduction of 60% to be made in the quantity of exothermic material required to give a flat feed.

As an alternative to this type of tile, the authors have considered the use of a headbox with a replaceable insulating lining, which can be faced with exothermic material for each cast. We have always found that, whilst many steelmakers initially are enthusiastic about replaceable linings, in practice a cheap, simple, expendable hot-top is more convenient at the pit-side. We are working on this, but should replaceable linings be required, it is possible to provide them now. The authors have drawn attention to a number of drawbacks in applying an exothermic facing for each cast; they state that the number of operations is excessive and that it is difficult to apply the facing uniformly and to dry it out after application. Two recent advances, however, should go a long way towards overcoming these drawbacks; first, exothermic facings can now be applied by spray gun, with greater ease and uniformity, and secondly, they can be made self-drying. This avoids the need for stoving as the exothermic material dries itself out at a temperature of about 120° C.

Finally, whilst agreeing generally with the authors regarding aluminium pick-up, the source of which is most probably the anti-piping compound used, we would point out that the degree of contamination is never of such an order as to make the use of exothermics prohibitive, and often is no greater than the limits of analytical error.

Mr. **J. C. Carpenter** (Ferro Engineering, Cleveland, Ohio): I should like to take the opportunity to discuss these two excellent papers, as they are of great interest to those of us who are concerned with the hot-topping of steel ingots.

Ferro Engineering designs, manufactures, and markets C & D hot-tops, which are used by the majority of killed-steel producing plants in the U.S., Canada, and some European countries.

These two papers present a very comprehensive study of the hot-topping of 5-cwt ingots in the laboratory. While we agree in general with the metallurgical findings of the authors, we would like to point out that by our methods, in contrast to their findings, excellent lining lives can be obtained with insulating brick in C & D low-volume hot-tops.

Some eight years ago, we began experimenting with hot-top linings of insulating firebrick, and developed a method for protecting them. Tests on production ingots in several steelworks confirmed a primary mill yield saving of at least 3%, and lining lives at least equal to those obtained with regular firebrick linings. This work resulted in our development of the C & D low-volume hot-top.*

The process and its results were described in a paper;† in the discussion which followed, it was stated:

"There are conventional hot-tops, the semi-permanent tops such as the C & D, the electric hot-top, the gas hot-top, and in addition the use of super-exothermic mixes in hot-tops, each striving for the same goal of creating an ingot with the least possible discard. A point of major importance in considering what to use resolves itself, after some serious experimentation, in the use of the method that will give the most consistent yield with the simplest shop technique. The idea presented by this paper appears to offer this in our shop."

"We embarked on the use of the low-volume C & D hot-top in 1951 pouring 25 in. sq. ingots weighing 9000–11000 lb. Since that time, many thousands of ingots have been poured in all grades of alloy steel, with very satisfactory results. In 1953 a 19¼ in. sq. ingot was started and now all steel is poured in these two sizes which encompass more than 90% of the melted tonnage."

"Naturally the average person familiar with refractories would view with alarm the use of insulating refractories in as rough service as hot-topping, but with proper application of the facing of veneer, actual service life of the insulating firebrick exceeds that of hard brick. Patching techniques for the linings are simple because of the easy forming characteristics of this brick."

This original installation of C & D low-volume hot-tops has been followed by other commercial installations which together produce some 1,155,000 gross tons of ingots per year, using this process. Ingots of 2·4–12·7 gross tons with hot-top volumes of 9–13% are used, the volume depending on type and size of ingot, as well as

* British Patent No. 708,599.

† A.I.M.E. Proc. Elec. Furn. Conf., 1954, pp. 156–162.

quality requirements. In all cases, the insulated hot-top volumes are at least 3% less than with the same type of hot-top formerly used with regular firebrick linings, and a minimum of 3% increase in primary mill yield is being obtained, with comparable steel quality. In many cases one extra ingot per heat is obtained. Grades of steel being produced include all electric-furnace and O.H. carbon steels up to 1·10% of carbon, alloy, and stainless steels, and the high-quality carbon–chrome bearing steels which normally require high hot-top volumes.

In these operations, the hot-top lining life varies from 30 to 50 heats per lining, with a life of 50 currently being obtained on a large slab hot-top for an ingot 30 in. × 54 in. in top cross-section, and weighing 12·72 gross tons. The average saving in cost per ton of finished steel in the plants which are now using low-volume hot-tops, instead of regular hot-tops with conventional hard firebrick linings, is 4*s*. 6*d*.

Mr. **H. Woolfson** (London and Scandinavian Metallurgical Company, Ltd.): I have read the papers with much interest, particularly the one on heat flow, because I agree with Mr. Fenton that it is surprising that so little study has been given to this subject.

The relative desirability of re-usable or single-life hot-tops has often been discussed and, in company with many steelmakers, I feel that, provided the refractory lining has an adequate life, there is much to be said in favour of the re-usable top.

It is unusual to be able to apply theory wholly to practice; an instance of this is found where wide-end-up ingots are cast on bogies. In this case it is necessary to have an appreciable amount of metal left in the head solely to provide a 'handle' for the stripper, quite irrespective of metallurgical factors. Thus the optimum is the smallest head which will give the desired metallurgical result whilst at the same time leaving sufficient metal for gripping.

The use of an insulated lining, much as described by Mr. Fenton, provides, in my opinion, the best compromise, and our only point of disagreement is in connection with lining life. However, this point is fully covered by Mr. Carpenter, and it would appear that the U.S.A. have moved well ahead of us.

Mr. **W. A. Jenks** (Lancashire Steel Corporation Ltd.): One of the aims of tonnage steelworks today is to improve primary yield from the ingot without any reduction in metal quality, and work of this nature being carried out by B.I.S.R.A. is a great help.

Several points arise out of these papers which emphasize the importance of considering the practicability of the various hot-topping devices. First, while it is advantageous to reduce the head volume and obtain more efficient feeding, the head must be of an optimum size for ease in stripping. The question of track times must also be borne in mind; if the hot-top develops an exothermic reaction or keeps hotter longer by insulating means, the track time of the ingots into the soaking pits must of necessity be lengthened. Finally, the question of cost must be considered; when large tonnages of plain carbon steels are involved, it may often prove more economical to scrap some steel rather than bear the cost of expensive hot-topping in order to obtain an improved yield. The role of exothermic materials in alloy-steel casting represents the opposite viewpoint to this.

We have been using the C & D type hot-top with a head volume of 14%, on wide-end-up moulds for several months now, and mainly for plain carbon steels in the range 0·60–0·80%C. We find these heads give consistent results as regards yield and metal quality, and certainly from the viewpoint of lining life and the absence of 'hanger crack' troubles they are a big improvement on our previous superimposed-type feeder heads.

However, as a tonnage shop casting a considerable quantity of steel in narrow-end-up moulds, we are anxious to find some method of improving the primary yield from this type of ingot, with a subsequent improvement in metal quality. We have experimented with exothermic-type sleeves and slabs representing head volumes of 7–10%, but so far we have not found a practical type of insert or top which can be incorporated with these moulds to give consistent results. Everybody will agree that the narrow-end-up mould is far from being the ideal shape from the viewpoints of piping and segregation but owing to the ease with which such ingots can be stripped they are a natural product of a tonnage shop. It would be interesting to hear if the authors have carried out any investigations in this field.

Mr. **H. O. Howson** (David Brown (Industries) Ltd.): The techniques described, although widely applied in non-ferrous practice, have to date aroused little interest in steel ingot production. The clear distinction that is maintained between the practical and theoretical approaches is praiseworthy, and in the latter connection the reliance placed on actual pyrometric observations in preference to a mathematical approach is in line with recent thought.

The complete elucidation of the thermal balance in a feeder head is an ambitious undertaking, and it is suggested that as a preliminary measure the fundamental relationship between liquid steel and a refractory container should have been studied on the lines used by Bishop, Brandt, and Pellini.*

These investigators made heat-flow measurements by the 'thermal analysis' method (using inserted pyrometers) for chill and sand walls at the mid-height of a wide-end-up mould 20 in. × 7½ in. sq. top × 6½ in. sq. bottom, and gave the following data on the time for complete solidification of a 0·60% carbon steel cast into moulds of varying wall thickness:

Wall thicknesses, in.	1½	2½	4½	7
Period of complete solidification with cast-iron chill walls, min.	11½	10½	10	...
Period of complete solidification for sand mould in a ¼ in. thick mild-steel box, min.	...	44	48½	49½

These results indicate that for a sand mould in a ¼-in. mild-steel box, an increase in sand thickness from 2½ to 4½ in. delays the solidification time from 44 to 48½ min, an increase of 10%. A further increase in thickness to 7 in. produces a negligible (2%) increase in solidification time. The American authors refer to the 4½-in. sand wall as a 'sufficient thickness,' i.e. sufficient to absorb substantially the heat liberated between teeming and solidification. A greater sand-wall thickness is inconsequential, but a reduction in thickness leads to a decrease in solidification time, as the mild-steel container then plays an important part in heat abstraction. It is considered that the series of papers on heat transfer published by the U.S. naval research scientists are of vital importance, and it is suggested that fundamental work on these lines should be carried out by B.I.S.R.A. A factor requiring experimental investigation is the effect of an air-gap between the refractory and the mild-steel box on the heat abstraction characteristics in hot-tops.

The suggestion of a 4½-in. sand wall as a 'sufficient' thickness may be contrasted with the somewhat vague recommendations of the B.I.S.R.A. workers of a ½–2-in.

* *Trans. A. F. S.*, 1951, vol. 59, pp. 435–447.

refractory wall for a 7½ in. sq. feeder head, but I agree with the authors that the practical thickness should be determined, not by heat-flow considerations (which are of minor importance over the possible range of wall thicknesses), but to present the minimum refractory bulk (and, therefore, cost) that is consistent with manufacture.

My personal recommendation is as follows:

Feeder-head base diameter (or distance across flats), in.	Total refractory wall thickness, in.
up to 8	1
8–12	1¼
12–16	1½
16–20	1¾

A method of reducing further the bulk of refractory, and at the same time increasing the life by the elimination of spalling, is to introduce recesses into the back of the tile. It is suggested that this method is valuable when the works practice admits no alternative to the firebrick slab.

A conclusion from the second paper which is in line with experience both in the non-ferrous industry and also overseas, is that although an increase in yield may be obtained by the direct application of insulating brick or exothermic methods, the cost of the materials is greater than the saving in liquid steel, except for small ingots or highly specialized materials and techniques. In consequence, efforts have been concentrated on the development of a duplex form of construction of which examples are given in the paper. The writer submits, however, that the most logical approach is to utilize the strength and rigidity of the conventional refractories in the form of a protective shell, and to introduce an insulating or exothermic material into the recess moulded into the back of the tile. The full implications of this technique have not been utilized to date in commercial practice, but on an experimental basis it has been possible to manufacture recessed tiles with an effective wall thickness of 3/16 in. The small bulk of refractory employed has permitted the economical use of the expensive high-alumina refractories (such as sillimanite), and these have a long life. This will permit the economical filling of the recess with vermiculite or other highly insulating material.

Alternatively, recessed tiles may be produced very rapidly and cheaply from silicate CO_2-bonded sand by the core-blowing process to give an economical and expendable tile. The recess can be filled with exothermic mixture backed by insulation, and this method has the advantage of introducing the exothermic action, without complicating the pit-side work or introducing contamination.

Progress in these improved feeding methods is primarily dependent on the provision of accurate costs, and it is suggested that a desirable (and possibly essential) departure is the standardization of feeder-head dimensions. Although feeder-head thermal efficiency is an important factor, this must be blended with the following considerations:

(i) Availability and convenience
(ii) Feeder-head cost per ton of steel
(iii) Metallurgical quality of the ingot.

Furthermore, as the same design of feeder head has to be available for steels of different compositions and, therefore, different solidification characteristics, it is felt that a purely empirical design is dictated, and the following three basic designs are submitted:

	length/diameter ratio	Taper, in. per ft.	Cross-section
(*a*)	1·5	1	Octagonal
(*b*)	0·75	3	Square
(*c*)	1·1	1	Square

Design (*a*) presents the well-known thermal efficiency of the tall, narrow feeder head which has obvious applications. It is known, however, that these virtues are only shown in connection with steels of a narrow freezing range, and with the highly alloyed steels design (*b*) is almost essential to secure reasonable axial soundness. Design (*c*) is submitted as a compromise for general purposes. These three basic designs would be required in basal diameters ranging from 8 to 20 in., in steps of 1 in. It is submitted for the attention of B.I.S.R.A. that standardization on these lines is an essential pre-requisite of the comparison of costs of improved feeder-head practice, and is in line with the standards for ingot moulds and casting-pit refractories recently issued.

To return to the more theoretical aspects of the paper, the solidification time of a 9 in. sq. ingot is 20 min. and for the 7½ in. sq. feeder head 23½ min. The data submitted by Bishop, Brandt, and Pellini are: 7 in. sq. chill ingot—11½ min.; 7 in. sq. refractory-walled container—48½ min., and indicate the well-known fact that steel in a refractory mould is solid in about five times the period required in a chill mould. The B.I.S.R.A. results show only a small increase in solidification time in the feeder head as compared to the chill, and I submit therefore, that heat transfer between the feeder head and the chill ingot is of greater importance than is borne out in the present papers. There are thus grounds for instituting a complete pyrometric survey of the chill and feeder-head portions of the ingot, and although this is a large-scale project, the results would carry more complete conviction.

Although heat flow is important, it must be realized that ingot solidification is primarily a phenomenon of dendritic growth, and that some of the dendrites probably have freedom to move under gravitational or convectional forces. Although there is every indication that a high thermal input to the feeder head is beneficial from the discard aspect, the effect on ingot soundness and segregation requires a more thorough investigation than has been given to date.

AUTHOR'S REPLY

Mr. **G. Fenton:** We have found these comments most interesting and would like to thank all the contributors. Many of their remarks illustrate clearly that it is impossible to put forward any one hot-topping procedure which would be ideal for all killed-steel ingot makers, as casting-pit layout and the practical and economic aspects of hot-topping vary so widely between works. We have, for instance, the question of the relative desirability of one-life and re-usable hot-tops, with opposite viewpoints presented by Mr. Cherry, and by Mr. Ash and Mr. Woolfson; the question of making full use of the increased yield, discussed by Mr. Campbell; and the doubts raised by Mr. Ash, Mr. Campbell, Mr. Jenks, and Mr. Howson that some of the more efficient methods could not be applied economically to certain types of steel. It is precisely for reasons such as these that we gave only general recommendations and made no attempt to list the various hot-topping methods in any order of preference. We have given an idea of the results that can be expected from different techniques, and we suggest that the steelmaker should now make his own assessment, taking into account the conditions in his own particular works.

Mr. Campbell raises two points on the question of making full use of the metal saving.. We agree fully that these considerations are vital. There is, perhaps, one point to add, and that is that very often a butt ingot remains at the end of a cast, and a saving in metal of

less than an ingot weight might be sufficient to bring this butt ingot up to saleable weight. The butt ingot (or, more accurately, the *average* butt ingot) should also be considered in Mr. Campbell's second point.

As stated in the second paper, we have detected aluminium pick-up extending into the body of the ingot in some cases, but since the paper was written we have looked into the matter more deeply. In certain cases where feed efficiency was inadequate due, for instance, to too small a head volume or too thin an exothermic facing, then pick-up could extend into the ingot body and appeared to coincide with the zone of major segregation. When conditions were correct and the flat feed obtained, both major segregation and aluminium pick-up were confined to a narrow layer at the extreme top of the head. Outside this zone, the total aluminium level did not differ significantly from that of the pit sample. It seems, therefore, that any excessive aluminium pick-up would be removed in the normal top crop.

On the question of flotation of inclusions, the two heat balances showed that ingots with firebrick and insulating-brick hot-tops had almost indentical freezing times. One would not expect, therefore, any significant difference in this flotation. It is possible that the highly exothermic hot-tops will delay the freezing of the ingot to some extent, but the inclusion content of the ingots has not been checked directly.

We found thin layers of ganister or fireclay to be quite adequate for protection of the steel sheet in the double headbox. The application of flame-sprayed cermets might have possibilities, however, and will be borne in mind.

Mr. Cherry gives some interesting information on the latest developments in the field of highly exothermic materials. The 'round-to-square' design is particularly interesting and seems to be a good compromise on head shape. The latest results which he quotes on composite tiles with insulating backing are very encouraging and the 60% reduction in the necessary quantity of exothermic material should mean that it can be applied economically over a wider range of steel types.

In reply to Mr. Cherry's query, we confirm that the mildly exothermic top additions, which we do not expect to give any real improvement over pure insulating additions, are the carbonaceous types. In using this type of material, we found no significant pick-up of carbon in the ingot body itself. Any pick-up, which was very small, was confined completely to the head region.

Mr. Carpenter, Mr. Woolfson, and Mr. Jenks all refer to the C & D floating hot-top. The characteristics of this design, and its important ability to reduce hanger-crack occurrences, are, of course, more in the nature of mechanical aspects of hot-topping rather than the thermal aspects with which we were primarily concerned. We consider the C & D top to be a well-engineered design which has a number of very desirable features.

Looking at the thermal aspects, the main reason why the C & D hot-top could be more efficient, lining for lining, than the conventional superimposed hot-top is that, being a floating hot-top fitting within the mould, it will be narrower in section than the conventional design. Therefore, as our results show, it will lose less heat to the ingot. Another reason is that the C & D top follows the ingot as it shrinks, so there is no danger of the extreme base of the head leaving the hot-top and radiating directly to the ingot mould.

The lining life obtained with the insulating-brick C & D hot-tops is indeed remarkably good. This is presumably due in part to the good support provided by the headbox, which we also found essential, and by the sand ring, but mainly to the refractory veneer which is renewed for each heat. We considered the application of a protective facing for insulating bricks but were not too optimistic because of the extra labour involved and, more particularly, because of the facing's effect on thermal conditions. In a hot-top in use, a steep thermal gradient through the brick exists—the more insulating the brick, the steeper the gradient. It is easy to see then, that the heat contained in the brick is largely concentrated near the hot face and, therefore, the protective facing will be placed at exactly the position where it will be most detrimental thermally. We calculated, for instance, that a ¼-in. layer of dense fireclay applied to the 1½-in. insulating brick would increase its heat content in service by about 40% and, therefore, tend to nullify the lower heat capacity of the insulating brick. We have no knowledge of the nature of the C & D veneer but it seems likely that it is not as dense as we felt was necessary; and even allowing for the benefit derived from the narrow section, it is quite obvious from the results quoted by Mr. Carpenter that the veneer has not reduced the efficiency of the insulating brick to any great extent. Lining life equal to, or even exceeding, that of firebrick linings means that the main objection hitherto to insulating-brick linings has been overcome, and Mr. Carpenter and Mr. Woolfson are to be congratulated on this advance.

Mr. Woolfson and Mr. Jenks both draw attention to possible stripping difficulties with the very small residual heads in exothermic hot-topping. This is, of course, yet another mechanical aspect which we have encountered previously and one which must certainly be faced. Mr. Cherry has described techniques which have been successfully applied, however, and which seem to meet this objection, at least with the smaller sizes of ingots of about 1 ton.

Mr. Jenks also mentions a possible drawback of longer stripping and track times when using the more efficient hot-tops. Here we would point out that there is no benefit to be gained in excessively prolonging the freezing time of the head beyond that of the ingot, and that is one reason why we suggest that the more efficient the hot-top lining, the narrower the hot-top should be. In other words, the section of the head, whatever the lining, should be adjusted so that its freezing time is not excessively greater than that of the ingot, and therefore, the stripping and track times need not be increased. Here, however, the question of the acceptable shoulder width arises.

The question of hot-topping narrow-end-up ingots is also raised by Mr. Jenks. All our investigations have been connected with wide-end-up ingots but the theory, at any rate, still applies; a given refractory will abstract heat from steel in the same manner regardless of the shape of the ingot beneath it. The main difference between narrow-end-up and wide-end-up ingots lies in the formation of a 'bridge' in the former type, resulting in primary and secondary pipes. As the total shrinkage must be the same in both types of ingot, other conditions being the same, the primary pipe in a narrow-end-up ingot will be smaller in volume than that in a wide-end-up ingot. Some works trials on narrow-end-up hot-topping have suggested that there is a certain level of thermal efficiency which prevents or delays the formation of the bridge, reducing the volume of secondary pipe at the expense of an increased primary pipe and, therefore, increasing the top discard. This would indicate that one must either ensure early formation of the bridge and rely on complete welding of the secondary pipe during rolling (and it is a fact that very good yields can be obtained with certain narrow-

end-up killed ingots with no hot-topping at all), or use a very efficient hot-top which not only prevents secondary piping by not allowing the bridge to form, but also keeps the primary pipe well up the ingot in the form of a wide, shallow cavity. This depends to a large extent, of course, on the degree of taper on the ingot. A number of works experiments on narrow-end-up hot-topping are currently in progress and it is hoped that the results will become available.

There seems to be some doubt in Mr. Howson's mind about the validity and accuracy of our heat balances, otherwise it is difficult to see why he considers we should have first carried out preliminary work on the lines of Bishop, Brandt, and Pellini. We do not claim absolute accuracy but we are quite satisfied that our heat-flow measurements are sufficiently accurate, and give sufficient information, for our purpose. The very good agreement between the 'total heat' curves in Figs. 3 and 4 of the first paper supports this view. For the same reason, we do not feel that a more complete pyrometric survey, suggested by Mr. Howson, would add anything of real practical value to the information we have already obtained. A more complete survey, by which Mr. Howson presumably means using even more thermocouples, might increase the accuracy of the heat balance, but we have already achieved an accuracy which we consider to be adequate. We would suggest that further heat-flow measurement work should be directed towards larger ingot and head sections with appreciably longer freezing times, rather than to the relatively small sections to which we are limited at the B.I.S.R.A. Sheffield laboratories.

Mr. Howson considers our recommendations on firebrick thicknesses to be somewhat vague. The reason for the wide range in thickness is that, within this range, differences in total heat abstraction are negligible; as the brick thickness is decreased within the recommended range, its decreasing heat content is almost exactly counterbalanced by the increasing heat loss from the cold face. We suggest, then, that the steelmaker chooses the brick within this range that gives him the lowest refractory costs, taking into account both the initial cost of the bricks and their life; this does not necessarily correspond to the minimum refractory bulk, as Mr. Howson states. We would point out also that these recommendations are based on actual measurements in refractories with simulation of a headbox and with the small air-gap between brick and box which is almost impossible to avoid in practice. Mr. Howson himself puts forward suggestions on brick thickness, but gives no indication on whether they are based on theory or on measurement. It is noticeable that they lie within the range we suggest and do not agree with the 4½-in. thickness quoted by Bishop, Brandt, and Pellini.

Some of the differences between our results and those of Bishop, Brandt, and Pellini are undoubtedly due to the different conditions adopted. The American workers obtained their results on sand walls by measurements at mid-height in an ingot cast in a sand mould; our measurements, from which we quote the freezing time of the head, were taken near the base of the hot-top and will obviously be affected by the heat loss to the ingot. In addition, the hot-top during solidification loses about 20% of its steel content to the ingot; its surface level is continually dropping so that heat losses from the top surface must also affect the freezing time near the base. We can see no justification for Mr. Howson's suggestion that our estimation of heat loss to the ingot is low.

Our heat-flow measurements suggested that recessing a firebrick tile would give no significant decrease in total heat abstraction, and this was supported by the trials reported in the second paper. Filling the recess with a good insulating material would certainly reduce the loss from the cold face but would also raise the thin refractory to a higher average temperature. This would not only increase the heat content but might very well lead to earlier failure. This consideration, in fact, led to the development of the double headbox. If the more expensive high-alumina refractories can be used economically, however, as Mr. Howson suggests, then the idea of a recessed tile with insulation backing would seem to be more promising.

The idea of filling the recess with exothermic material, however, does not seem to be very practicable. Mr. Howson states that the exothermic action could be introduced in this way, without complicating the pit-side work or introducing contamination. First, regarding contamination, we would refer to our reply to Mr. Campbell; and secondly, we cannot visualize any savings in labour in the casting pit. The exothermic filling would, of course, have to be renewed for each use, and as the recessed brick would presumably be held in a headbox, the operation would be complicated indeed. In the case of an expendable recessed sand tile, the pit-side labour involved would be no different from that with a conventional exothermic hot-top. We would suggest that where the cost of the exothermic material is justified, it should be used at the hot face, where it will give the most benefit; interposing refractory or sand between it and the liquid steel will greatly reduce its effect.

Although we agree with Mr. Howson on the importance of hot-top costing we think his suggestion of standardizing hot-top designs is rather ambitious. Some standardization in ingot size and shape would be required first; one would also have to take into account the teeming conditions, which can affect pipe formation appreciably and thereby affect the volume of hot-top required. Then presumably one would also require standards for each of the many different hot-topping methods available. The very wide differences in conditions at different steelworks would make it as difficult to standardize on hot-top design as it is to recommend any one hot-topping method. The idea would be simpler if one considered only the conventional brick hot-top; but the latest advances in exothermic materials reported by Mr. Cherry, and the very good performances of the insulated C & D hot-top reported by Mr. Carpenter and Mr. Woolfson, show that both exothermic materials and insulating bricks are now capable of a much wider application.

Regarding Mr. Howson's three basic designs of hot-top, we have no data on the effect of hot-top taper and it would seem that here is another aspect which should be studied further. On the question of cross-section, Mr. Howson's octagonal and square sections may be simpler to manufacture, but from the viewpoint of thermal efficiency we would suggest the circular section. If shoulder difficulties are anticipated, then Mr. Cherry's 'round-to-square' design would seem to be the best. The pronounced differences in length/dia. ratio and taper between Mr. Howson's designs (*a*) and (*b*) is rather surprising; design (*b*) is intended to ensure axial soundness in highly alloyed steels and it would be interesting to know on what evidence it is based. It should be remembered that ingot taper, teeming speed, and teeming temperature all have pronounced effects on axial soundness. A more detailed study of the feeding of steels with widely different freezing ranges would certainly be useful, but it is already known that good-quality ingots can be produced with the newer and more efficient techniques of hot-topping. They are in routine use in some works already with a variety of steels, including the highly alloyed types.

N E W S

Announcements and News of Science and Industry

THE IRON AND STEEL INSTITUTE

Honorary Vice-Presidents

It was announced during the recent Special Meeting in Belgium and Luxembourg that the following had been elected Honorary Vice-Presidents of the Institute:

Monsieur Léopold Bouvier (*President, Groupement des Industries Sidérurgiques Luxembourgeoises*)

Monsieur François Perot (*President, Centre National de Recherches Métallurgiques*)

Monsieur Pierre van der Rest (*President, Groupement des Hauts Fourneaux et Aciéries Belges*).

NEWS OF MEMBERS

Birthday Honours

C.B.E.—Mr. **N. R. R. Brooke** (Guest Keen and Nettlefolds Ltd.)

Mr. **T. C. Bailey** is to take office as President of The Institute of Fuel in October next.

Mr. **L. A. Fullagar,** a Technical Director of McLellan and Partners, retired at the end of March after 34 years with the firm.

Mr. **P. F. Grove** has been appointed a Technical Director of McLellan and Partners.

Mr. **H. M. Henderson** has been appointed Managing Director of Unisteel Structural (Pty.) Ltd., of Capetown; this company, which is now a wholly owned subsidiary of United Steel Companies Ltd., was formerly known as Patchett Steel Constructions (Pty.) Ltd. Mr. Henderson has also been appointed a Director of Unisteel Africa (Pty.) Ltd., of Johannesburg.

Mr. **R. F. Jennings** has been appointed Technical Director of Huntington, Heberlein and Co., Ltd.

Dr. **R. F. Mehl,** of Carnegie Institute of Technology, has been elected a member of the National Academy of Sciences, Washington, D.C.

Mr. **A. G. B. Owen,** C.B.E., has been re-elected President of the National Union of Manufacturers (Midland Branch).

Mr. **E. Ross** has left the Armament Research and Development Establishment, Woolwich, to become a Senior Scientific Officer with the U.K.A.E.A. Industrial Group, Research and Development Branch, Preston.

Mr. **J. Thomson,** Melting Shop Manager at the Dalzell Works of Colvilles Ltd., for the past 17 years, has retired.

Obituary

Mr. **William Hunt Eisenman** (*Honorary Member; elected* 1955), Secretary of the American Society for Metals, of Cleveland, Ohio, on 30th May, 1958.

Mr. **Cecil Walter George** (*elected* 1917), of Farnborough, Hampshire, on 25th April, 1957.

Dr. **Polykarp Herasymenko** (*elected* 1938), of New York, on 6th April, 1958.

Mr. **Frederick Rose** (*elected* 1953), of Keston, Kent, on 2nd May, 1958.

Dr. **George Vincent Slottman** (*elected* 1930), of New York, on 21st April, 1958.

Mr. **Arthur Henry Waine,** F.I.M. (*elected* 1937), of Sheffield, on 4th May, 1958.

CONTRIBUTORS TO THE JOURNAL

I. Backhurst, M.SC.—Principal Scientific Officer, Physics Division, National Physical Laboratory.

Mr. Backhurst was born in 1899 at Guildford and educated at the Royal Grammar School there. He entered University College London in 1916, but his studies were interrupted from 1917 to 1919 by war service. On returning to University College he was awarded the Neil Arnott Scholarship with bronze medal in June, 1919; the following year he graduated with first-class honours in physics and obtained the Trouton Research Scholarship. He worked as a part-time demonstrator at the College until 1921, when he was appointed a D.S.I.R. investigator under Sir William Bragg; in 1922 he was awarded the Carey Foster Research Prize, and also obtained the degree of M.Sc. In the same year he joined the Physics Division of the N.P.L. as a junior assistant.

Until the second World War, Mr. Backhurst was engaged chiefly on X-ray research under Dr. Kaye; during the period of hostilities he was working in the Laboratory's Metrology Division. Since the war he has been with the Heat Section of the Physics Division.

(*Mr. Backhurst was the author of a paper in the June issue of the Journal*).

D. I. Cameron, B.A. (CANTAB.)—Research Superintendent, Lysaght's Central Research Laboratory, Newcastle, N.S.W., Australia.

Mr. Cameron graduated from St. John's College, Cambridge, with B.A. Honours (Natural Sciences Tripos) in 1931. He has been on the research staff of Lysaght's Works Pty. Ltd., since 1938; he became Research Superintendent in 1955, when Lysaght's Central Research Laboratory was established.

W. S. Gibson, B.A. (HONOURS)—B.I.S.R.A. Bursar, Department of Metallurgy, Oxford University.

I. Backhurst

D. I. Cameron

W. S. Gibson

M. W. Lightner

Mr. Gibson was born at Wallasey in 1933; he was educated at Wallasey Grammar School and Brasenose College, Oxford, where he read chemistry. He was awarded the degree of B.A. (Honours) in 1955. He is at present holder of a B.I.S.R.A. bursary, and is working in the Department of Metallurgy, engaged in research on the freezing and melting points of iron alloys.

M. Hillert, SC.D.—Swedish Institute for Metal Research, Stockholm.

Mats Hilding Hillert was educated at the Chalmers Institute of Technology, Göteborg, where he graduated in 1947. He joined the Swedish Institute for Metal Research in the following year, and has been engaged chiefly on research in physical chemistry. He spent three years' leave at the Massachusetts Institute of Technology, obtaining the degree of Doctor of Science in 1956.

M. W. Lightner, M.S.—Vice President, Applied Research, United States Steel Corporation.

Dr. Lightner gained his B.S. degree in 1929 at the Pennsylvania State University; in the following year he was awarded an M.S. degree in Metallurgical Engineering by the Carnegie Institute of Technology. He remained with the Carnegie Institute as Research Engineer until 1933, when he joined the Carnegie-Illinois Steel Corporation as Assistant to the Chief Metallurgist. In 1940 he was appointed Assistant to the General Superintendent of the Homestead District Works of the Carnegie-Illinois group.

For a time during the war Dr. Lightner was First Vice President of Operations at the Heppenstall-Eddystone Corporation and later Director of Research at the Heppenstall Steel Company. He rejoined Carnegie-Illinois in 1944 as Assistant Manager of the Research and Development Division and was appointed Manager of this division in the following year. He joined the United States Steel Corporation in a similar capacity in 1951, and became Assistant Vice-President of Research and Technology in 1954. He was appointed to his present post in 1956.

D. L. McBride

D. L. McBride, A.B., M.S., D.SC.—Director, Metallurgical Process Development and Applied Research, United States Steel Corporation.

David L. McBride graduated from the Carnegie Institute of Technology and joined the Bethlehem Steel Company in 1935 as a research engineer. In 1951 he joined the National Academy of Sciences in Washington to work on methods of conserving and increasing supplies of strategically and critically scarce metals and minerals. Dr. McBride joined the United States Steel Corporation in 1953 as Supervisor of Research Associates in the Research and Technology Division. He is at present engaged in research and development work in process metallurgy.

AFFILIATED LOCAL SOCIETIES

North Wales Metallurgical Society

The following officers and committee were elected for the 1958–1959 session at the Annual General Meeting on 28th April:

Chairman
H. Brooke Freeman
Vice Chairman
H. Edwards

Treasurer	*Auditor*
S. Andrew	L. S. Taylor
Hon. Secretary	*Assistant Secretary*
S. Weir	J. B. Edwards

Press Secretary
H. M. Newbery

Committee

M. A. Hall	G. Millington
E. D. Harry	A. D. Osborne
H. H. Johnson	E. Taylor-Austin
R. Mayorcas	R. L. Willott

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Annual Report for 1957

The Annual Report of the Association for 1957 was published recently. It describes a full year's research into the many and varied problems that lie ahead for the industry. There has been a thorough reappraisal of research on the use of fuel and power in the light of the current uncertainty about the quality and quantity of future fuel supplies. More emphasis has also been placed on product research, particularly the finishing of flat products, and work on mechanization and automatic control has received a great deal of attention.

Notable work has been done during the year on projects such as the use of self-fluxing sinter, humidity control, and high top pressure (Ironmaking Division); the use of oxygen and continuous casting (Steelmaking Division); the mechanization of the forging process, extrusion, and automatic control of strip finishing (Mechanical Working Division); automatic control systems and all forms of energy (Plant Engineering and Energy Division); air pollution (Physics Department); and the sources of steelmaking fumes (Chemistry Department).

Copies of the Report may be obtained from the Association's Information Section, 11 Park Lane, London, W.1.

EDUCATION

B.I.S.F. Training Conference

The Tenth Training Conference organized by the Training Committee of the British Iron and Steel Federation is being held at Ashorne Hill, near Leamington Spa, from 16th to 18th July. The subject of the Conference will be "Training for Sales"; it is hoped to provide an opportunity for managers, senior administrative and commercial staff, and training officers to discuss developments in this field of training against the background of problems arising from changing market conditions and probable future trends in the industry.

AMERICAN SOCIETY FOR METALS

Changes in Executive and Staff

Resulting from the death of Mr. W. H. Eisenman (of whom an obituary notice will be published in a later issue of the *Journal*) The American Society for Metals has announced the following changes.

Mr. **R. T. Bayless,** former Assistant Secretary, is now Acting Manager of the staff, and is the person to whom routine correspondence should be sent.

Miss **Evelyn Gardner** is Secretary to the Board of Trustees and Secretary of the ASM Foundation for Education and Research.

Mr. **A. O. Schaefer,** a Past-President, is to be Secretary of the Society and Trustee during the unexpired term of Mr. Eisenman, ending October, 1958.

Mr. **W. E. Jominy** has been nominated as Secretary of the Society and Trustee for the term 1958–1960.

NEWS OF SCIENCE AND INDUSTRY

Managerial Appointments at United Steels

The United Steel Companies Ltd., have announced several senior managerial changes at the Appleby-Frodingham branch.

Lt. Cdr. **G. W. Wells,** at present Managing Director (engineering works) is appointed Managing Director (production), responsible to the general managing director. Cdr. Wells will continue as General Manager of the Appleby Frodingham Steel Company.

Mr. **A. Jackson** will relinquish his position as General Works Manager of Appleby-Frodingham to take up a new appointment as Technical Adviser on Steelmaking for the United Steel Companies. He will retain his directorship of Appleby-Frodingham, but will become Technical Director of that company.

Mr. **J. D. Joy** will relinquish his position of General Works Manager of Samuel Fox and Co., Ltd., and will move to Appleby-Frodingham as a Director and General Works Manager with a view to becoming general manager on 1st January, 1959.

New Mechanized Foundry at Dagenham

The new Thames Foundry of the Ford Motor Co., Ltd., is now in full operation. It consists of two buildings, one 1200 ft × 180 ft housing the main operations of melting, moulding, coremaking, and fettling, and the other, 700 ft × 70 ft, being used for sand handling, cooling, grinding, and cleaning. The planned daily capacity is about 400 tons of finished heavy castings, such as cylinder blocks, heads, and large tractor components.

The Institute of Fuel

The Annual General Meeting of The Institute of Fuel was held on 24th April; this was followed by the Annual Luncheon, at the Connaught Rooms, London. The President, Mr. H. McNeil, was in the Chair, and the principal speaker was Mr. W. Lionel Fraser, C.M.G.

T. C. Bailey

The next President of the Institute is to be Mr. T. C. Bailey, Sales Manager, (Industrial Fuels) of Shell-Mex and B.P. Ltd.; he will take office in October. Mr. Bailey, who is a member of The Iron and Steel Institute, will be only the second representative of the oil industry to hold this office.

Combined Desulphurizing and Sulphuric-acid Plant

The Appleby-Frodingham Steel Company has developed, after ten years of experiments and pilot-plant trials, an entirely new combined desulphurizing and sulphuric-acid plant; the first full-scale plant is now being installed and will be in production by the middle of next year. It is hoped that it will be capable of dealing with 32 million ft³ of gas daily.

The new plant, which is claimed to incorporate major advances on existing processes, consists essentially of a fluidized hot iron-oxide absorber and regenerator; it is capable of removing both H_2S and organic sulphur from coke-oven gas to a very low level. Heat requirements are met by combustion of the absorbed sulphur so that, once it has been started up, the plant is self-sustaining for heat. Since it uses hot gas, this process is much faster than the conventional process, whilst the use of fluidized beds reduces the amount of spent oxide considerably and simplifies its handling and distribution.

Two licensees for the new process have been appointed: Henry Balfour and Co., Ltd., of Leven, Fife, and W. J. Fraser and Co., Ltd., of Romford, Essex. The latter company is building the plant under construction at Scunthorpe.

Société Française de Métallurgie

This year's Journées Métallurgiques d'Automne of the Société Française de Métallurgie will be held from 20th to 25th October at the Maison de la Chimie, Paris. The two main themes of the meeting will be the influence of residual or trace elements on the properties and working of ferrous and non-ferrous metals, and the mechanism of fracture in metals. Full details may be obtained from the Société, 25 rue de Clichy, Paris IXe.

Coke-oven Contract

Gibbons Brothers Ltd., a subsidiary of Gibbons (Dudley) Ltd., have received from the South Durham Steel and Iron Co., Ltd., the contract to build the coke ovens for the new steelmaking plant to be constructed as an extension of their West Hartlepool Steelworks. This comprises three batteries of 78 'Wilputte' ovens, with complete oven machinery, coal and coke handling plant, and by-product plant. In addition orders have been received by Gibbons for the same development for large slab-reheating furnaces and one 220-ft continuous plant normalizing furnace. Completion of the first stage is expected early in 1960 and of the whole contract in 1961.

New Sheffield Works

The Rt. Hon. Lord Riverdale of Sheffield performed the opening ceremony on 5th June at the new Kingfield Works of Darwins Bright Steels Ltd. The new works was built in order that all the Company's wire-producing plant might be concentrated under one roof. It consists of five bays each 112 ft × 45 ft: a heat-treatment bay, with plant for spheroidizing, annealing, and quenching; a descaling bay; two wire-drawing bays; and a finishing and despatch bay.

N.I.F.E.S. Services

A booklet has recently been published by the National Industrial Fuel Efficiency Service giving details of regular service agreements. Under these agreements, plants are visited regularly by N.I.F.E.S. engineers, whose duty is to ensure that all fuel-using equipment is brought up to maximum efficiency and maintained at that level. Copies may be obtained from 71 Grosvenor Street, London, W.1.

Continuous Stainless-steel Mill

The first continuous mill rolling stainless-steel strip in the U.K. is now in operation at Shepcote Lane Rolling Mills Ltd. The new mill is a joint venture sponsored by Samuel Fox and Co., Ltd., and Firth Vickers Stainless Steel Ltd. It rolls strip up to 1 m wide and 400 ft long, in coils weighing 8500 lb each; the output is 30 coils per shift. It is fully automatic and only 18 men are required to operate it.

Welding and the Antarctic

The fact that the welded tracks of the Sno-cats used in the successful crossing of the Antarctic continent by the Commonwealth Transantarctic Expedition withstood the severe conditions to which they were subjected was largely thanks to research carried out by the British Welding Research Association. After trials in Norway had produced a number of weld failures, a thorough examination was carried out by B.W.R.A. It was found that the original welds had not been made under satisfactory metallurgical control, and so these were all machined out and rewelded according to a suitable heat-treatment cycle.

Changes of Title and Address

The name of Aero Research Ltd., Duxford, Cambridge, has been changed to CIBA (A.R.L.) Ltd.

The address of Vacu-Blast Ltd., is now Bath Road, Slough, Bucks (telephone Slough 24507–8–9).

Corrigendum

In the paper "*The Corrosion Resistance of Low-Alloy Steels*" by J. C. Hudson and J. F. Stanners (*J.I.S.I.*, 1955, vol. 180, July, pp. 271–284), the result quoted in Table II (p. 276) for steel no. 8, $\frac{1}{4}$-in. strip, exposed for 5 years, should be 13·4 and not 15·8 mils as given.

Industrial Publications Received

R. J. Hunt and Son, Ltd., have issued a colour brochure illustrating the range of their facilities for producing grey iron castings.

Conveyor and elevator belting is the subject of a new publication from B.T.R. Industries Ltd.

Electric furnaces for a variety of heat-treatment purposes are described in a leaflet from Royce Electric Furnaces Ltd.

Publication No. 74 from W.C. Holmes and Co., Ltd., is devoted to Holmes-Elex electrical detarrers.

The equipment for automatic proportioning of foundry core sand installed at the new foundry of the Ford Motor Co., Ltd., is described in a pamphlet issued by the Sinex Engineering Co., Ltd.

A new leaflet on hydraulic variable-speed gears has been issued by Carter Gears Ltd.

Hadfields Ltd., have recently published a booklet on extrusion press components (Publication No. 477).

P.R. "Uniform" pulley-mounted centrifugal fans are the subject of Publication No. 177 of The Standard and Pochin Bros., Ltd.

"Crusilite Electric Furnace Element" is the title of the latest brochure from The Morgan Crucible Co., Ltd.

CO-OPERATIVE TRANSLATION SERVICE

The following translations are now available, in addition to those given on p. 172 of the June, 1958, issue of the Journal:

604. Shorshorov: "Productivity and Thermal Efficiency of Processes of Heating and Fusing Metallic Sheets with the Flame of an Ordinary Linear Torch." (Source not known.) (£9).
661. Weineck: "The Economics of Heat and Power Utilization in a Mixed Ironworks, as affected by Technical Developments." *Stahl u. Eisen*, 1957, July 25th, pp. 988–998. (£6).
662. Stolzenberg and Tiemayer: "The Utilization of Energy in a Mixed Ironworks." *Stahl u. Eisen*, 1957, July 25th, pp. 998–1006. (£5).
703. Bezdenezhnykh *et al.*: "Development of Deoxidation Process of Rimming Steel." *Stal*, 1957, Aug., pp. 701–707. (£3).
705. Stupar: "Sulphur Exchange between Gas Phase and Bath of a Basic Open-hearth Furnace." *Stal*, 1957, Aug., pp. 707–712. (£3 10*s*. 0*d*.)
714. Koch *et al.*: "The Carbides and the Creep Behaviour of Cr–Mo–V Steel." *Arch. Eisenhüttenwesen*, 1957, Aug., pp. 445–459. (£5 10*s*. 0*d*.)
719. Hempel *et al.*: "Effect of Crystal Orientation on the Formation of Slip Lines on the Surface of Alpha–Fe Single Crystals subjected to Alternating Bending Stress." *Arch. Eisenhüttenwesen*, 1957, Aug., pp. 433–444. (£4 10*s*. 0*d*.)
739. Kopineck: "Rapid Determination of Iron in Slag" (with an accuracy of ± 2%, within 4 minutes). *Arch. Eisenhüttenwesen*, 1956, Dec., pp. 753–760. (£5).
770. Martin: "Control and Regulation of the Twin Drive of a Heavy Plate Mill." *Stahl u. Eisen*, 1957, Oct. 31st, pp. 1607–1610. (£2 15*s*. 0*d*.)
805. Kolosov *et al.*: "Improving the Quality of Ball-bearing Steel." *Stal*, 1955, May, pp. 431–438. (£5 10*s*. 0*d*.)
827. Hoffstadt: "A Forecast Method of Costing Applied to an Open-hearth Furnace Steelworks." *Stahl u. Eisen*, 1957, Oct. 17th, pp. 1488–1496. (£7 10*s*. 0*d*.)
828. Tselikov and Sarychev: "New Mill for the Manufacture o Welded Tubes with a Helical Seam." *Stal*, 1955, Sept., pp. 815–820. (£4).
839–843. "The Behaviour of Heat-resisting Steels during Creep Testing at 500–700° C." *Arch. Eisenhüttenwesen*, 1957, Nov., pp. 671–730.
839. Arwidson and Bihet: Group I—"Organization of Researches into the Long-time Creep Behaviour of Steel." (with discussion). pp. 671–677. (£3).
840. Olsson: Group II—"Experimental Equipment and Technique of Long-time Creep Testing." pp. 679–685. (£5).
841. (Discussion): Group III—"Evaluation of Long-time Creep Tests." pp. 687–694. (£5 10*s* 0*d*.)
842. Constant *et al.*: Group IV—"Results of Long-time Creep Tests on Ferritic and Austenitic Steels" (with discussion). pp. 695–715. (£10).
843. Schlüter *et al.*: Group V—"Scatter of Results of Long-time Creep Tests" (with discussion). pp. 717–730. (£8 10*s*. 0*d*.)
858. Seemann and Bentz: "Note on the Problem of the Classification of Defects by Ultrasonic Examination." *Rev. Mét.*, 1957, vol. 54, No. 7, pp. 529–537. (£3 10*s* 0*d*.).
860. Barats: "Increasing the Strength and Wear Resistance of Machine Parts by Roller-burnishing." *Metallov. i Obra. Met.*, 1957, No. 9, pp. 47–51. (£2 10*s*. 0*d*.).
863. Stich: "Electrical Resistance Heating for the Processing of Steel." *Stahl u. Eisen*, 1957, Apr. 4th, pp. 394–408. (£9).
873. Effenterre *et al.*: "A Replica Method for Optical Micrography and its Application to Non-destructive Examination." *Comptes Rendus Acad. Sci.*, 1956, Vol. 242, May 7th, pp. 2355–2357. (£1 10*s*. 0*d*.)
878. Kalinina: "Comparison of Metal Control for Hair-line Cracks in Billets and Finished Products." *Stal*, 1957, March, pp. 261–263. (£2 15*s*. 0*d*.)
879. Chaudron and Moreau: "Study of Hydrogen Brittleness in Iron (single Crystal Iron Cold-reduced and Tensioned)." *Métaux Corrosion-Usure*, 1943, vol. 19, No. 211, pp. 43–48. (£2 10*s*. 0*d*.)
894. Martiny: "Comparison of Wet and Dry Coal Preparation Methods, with Reference to the Preparation of Hungarian Coals and the Development of the Dry Method in Hungary." *Pub. Hung. Res. Inst. Mining*, 1957, No. 1, pp. 3–16. (£7 10*s*. 0*d*.)
904. Shapiro: "The Determination of Non-metallic Inclusions in Steel." Chapter 10 (pp. 112–116) of "The Metallurgy and Heat Treatment of Steel and Cast Iron; a Handbook," Metallurgizdat, 1957. (£2 10*s*. 0*d*.)
905. Popova: "Analysis of the Carbide Phases in Steel." Chapter II (pp. 116–118) of "The Metallurgy and Heat Treatment of Steel and Cast Iron; a Handbook," Metallurgizdat, 1957. (£2 10*s*. 0*d*.)
906. Speith *et al.*: "The Effect of Electro-inductive Agitation of the Bath on the Metallurgical Reactions in the Electric Arc Furnace." *Stahl u. Eisen*, 1958, Feb. 20th, pp. 215–220. (£5).
925. Moriguchi *et al.*: "Statistical Studies on Coal and Ore Sampling." *Ann. Rept. Eng. Res. Inst.*, Fac. Eng. Tokyo Univ. 1956, Sept., pp. 11–17. (£3).
927. Baranovskii and Pinus: "Automation of Open Hearth Furnaces by Electronic Apparatus." *Metallurg*, 1958, No. 2, pp. 15–17. (£2).
931. Müller and Dietrich: "Time Studies on a Blooming-slabbing Mill." *Stahl u. Eisen*, 1958, Apr. 3rd, pp. 397–406. (£6).
950. Köster *et al.*: "Internal Friction and Shear Modulus of Cold Worked and Re-crystallised Gold." *Z. Metallkunde*, 1956, Apr., pp. 224–228. (£3 15*s*. 0*d*.)
951. Haessner: "Determination of the Fibre Textures of Wires by means of a Counter-tube Goniometer." *Z. Metallkunde*, 1956, Sept. pp. 649–652. (£3).
962. Gagen-Torn: "The Rate Characteristics of Presses for Non-ferrous Metals." *Tsvetnie Metally*, 1957, Feb., pp. 61–67. (£3 5*s*. 0*d*.)

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

CONTENTS

Note: The letters *a*, *b*, and *c* refer to the three columns on the page concerned.

	PAGE
Mineral Resources	273a
Ores-Mining and Treatment	273a
Fuel-Preparation, Properties and Uses	274a
Air Pollution and Smoke	274b
Temperature Measurement and Control	274c
Refractory Materials	274c
Iron and Steel, General	275a
Blast-Furnace Practice and Production of Pig Iron	275a
Properties, Treatment and Use of Slags	276a
Direct Processes	276b
Production of Steel	276b
Production of Ferro-Alloys	277a
Foundry Practice	277a
Vacuum Metallurgy	280b
Reheating Furnaces and Soaking Pits	280c
Heat-Treatment and Heat-Treatment Furnaces	280c
Forging, Stamping, Drawing and Pressing	283a
Rolling Mill Practice	284a
Machinery for Iron and Steel Plant	284c
Welding and Flame-Cutting	284c
Machining and Machinability	286c
Cleaning and Pickling	288a
Protective Coatings	288b
Powder Metallurgy	289b
Ferrites, Cermets and Carbides	289c
Properties and Tests	289c
Metallography	291c
Corrosion	293a
Analysis	293c
Industrial Uses and Applications	294a
Historical	294b
Economics and Statistics	294b
Miscellaneous	294b
Book Notices	295a
New Publications	296b

*Abstracts, the reference to which is marked with an asterisk are, or are to be made available as translations.

MINERAL RESOURCES

Iron Deposits of the Eastern Pyrenees not Worked under Concessions. G. Vié. (*Echo Mines*, 1957, Dec., 713–715). Various abandoned workings are described, with analyses.

The Iron Sands of New Zealand. (*Min. J.*, 1958, **250**, Jan. 31, 131). Titanomagnetites, ilmenites and limonites are noted, with a brief review of attempts to establish the industry.

The Knob Lake Iron Ore Deposits. R. D. Westervelt. (*Can. Min. Met. Bull.*, 1957, **50**, Nov., 678–688). A Thesis.

ORES—MINING AND TREATMENT

The Economical Use of Bucket-Type Earth-moving Equipment in Quarries and Open-cast Ore Mining in Conjunction with Blasting Methods using Large-diameter Shotholes and Millisecond-delay Detonators, and Transport by Heavy Lorries. E. Mülot. (*Neue Hütte*, 1957, **2**, Dec., 717–731).—L. J. L.

Historical Aspects of Mineral Economy. M. Sala. (*Ann. Mines*, 1958, Jan. 3–52). A statistical and historical survey on trends in the mining industries since 1810, including coal and iron, showing a generally exponential period (1870–1913) followed by a period of fluctuations (1910–1950) with an analysis of two approaches to forecasting. An attempt is made to obtain general laws and various hypotheses are discussed—those of continuous expansion, S-curves, or alteration of fundamental factors.

Attempt to Forecast for 1965 and 1975 the Requirements for Iron Ores for the C.E.C.A. and Great Britain. J. N. Mathieu. (*Ann. Mines*, 1958, Jan., 53–61). U.S. production and imports and exports are taken into account.

Iron Ore in Spain. J. Balzola. (*Bol. Min. Indust.*, 1957, **36**, Dec., 581–586). [In Spanish]. The iron ores of Spain are discussed in terms of economic considerations. Similar comments are made upon the reserves, estimated to be of the order of 870×10^6 t; these contain about 50% Fe, about 370×10^6 t are haematite ores.—P. S.

On the Characteristics and Classification of Iron Ores. M. Prouza. (*Hutn. Listy*, 1957, **12**, (11), 1020–1026). [In Czech]. On the basis of developments in Soviet blast-furnace practice it is shown that existing classification of iron ores is inadequate to ensure maximum efficiency of the iron-making process. The various criteria which need to be taken into account in developing a more detailed method of ore classification, including physical, chemical and mechanical parameters, are discussed; a system for classifying ores is advanced and its shortcomings outlined.

Heating Experiments on Some Natural Titaniferous Magnetites. E. A. Vincent, J. B. Wright, R. Chevallier and S. Mathieu. (*Mineralogical Mag.*, 1957. **31**, Dec., 624–655). A report is presented of chemical, structural, magnetic and X-ray changes observed on heating ilmenites *in vacuo*.

Studies of the Hydrated Iron Oxides. II—Hydrated Ferric Oxide Minerals Altered from Pyrrhotite by Weathering. M. Nambu. (*Sci. Rep. Res. Inst. Tôkohu Univ.*, 1957, **9A**, Dec., 527–533). **III.—Hydrated Ferric Oxide Minerals Altered from Haematite by Weathering.** (534–537).

Method for the Determination of the Mineral Composition of Sedimentary Manganese Oxide Ores on the Basis of Their Thermal Properties. G. Grasselly and E. Klivenyi. (*Acta Universitatis Szegediensis, Mineralogica, Petrographica*, 1957, **10**, 33–46). [In English].

Electrographic Examination of Pulverized Ore Samples and Ore Concentrates. G. Grasselly. (*Acta Universitatis Szegediensis, Mineralogica Petrographica*, 1957, **10**, 25–31). [In English].

Mining in Scandinavia. C. Mamen. (*Can. Min. J.*, 1958, **79**, Jan. 67–77). **A: Kiruna Open Pit and Underground Mines. B: Malmberget. C: Boliden, Renström Mine and Långsele Mine.** Illustrated accounts with statistics.

Tracy Mine of Jones & Laughlin Steel Corp. R. W. Braund. (*Min. Eng.*, 1958, **10**, Jan., 88–90).

Iron Ore Handling and Preparation. T. H. Keen. (*Iron Coal Trades Rev.*, 1958, **176**, Jan. 24, 197–202). Practice at East Moors Works of the Guest Keen Iron & Steel Co. is described, especially the new ore handling plant and the use of conveyors.

Study of Optimal Efficiency in the Operation of Metal Ore Washeries. M. Leveau. (*Ann. Mines*, 1957, Dec., 791–796).

Laboratory Concentration of Chromite Ores, Red Mountain District, Kenai Peninsula, Alaska. R. R. Wells, F. T. Stirling, E. G. Erspamer and W. A. Stickney. (*U.S. Bur. Mines Rept. Invest.*, 1957, Dec., 5377, pp. 22).

The Humphreys Special Concentrator, Its Place in Ore Dressing. J. V. Thompson. (*Min. Eng.*, 1958, **10**, Jan., 84–87).

Metallurgical Properties of Ore-Coal Pellets. G. V. Gubin. (*Izvest. Akad. Nauk. Otdel. Techn.*, (6), 32–36). [In Russian]. Properties of pellets produced by pelletizing a mixture of 70% ore concentrates, 15% breeze, 15% slaked lime and a catalyst (promoting hardening by CO_2, composition not disclosed), and hardened by CO_2 in a stream of industrial waste gas were investigated. The composition of pellets: Fe40%, FeO(Fe_3O_4) 17·82%; C 13·9%; SiO_2 11·36%; Al_2O_3 0·4%; CaO 12·4%; MgO 1·26%. The following properties were tested and compared with those of a KMA sinter: reducibility at various temperatures, softening temperatures, mechanical strength (shatter test and crushing strength), before and after reducing heating to various temperatures, and gas permeability. The results obtained are given in tables and graphs.—V. G.

French Get Two-Layer Sinter Plant. (*Steel*, 1957, **141**, Dec. 23, 74–76). The design of a sinter plant to be constructed by Huntington Heberlein & Co. Ltd., is described. The process superimposes two layers on the strand. The bottom layer is for calcining only: the top layer sinters the calcined material and returned fines. Sintering air is preheated by burning blast furnace gas over the entire sinter bed. Advantages include fuel economy, low coke breeze consumption, stronger sinter. Certain limitations of the process have corresponding advantages.—D. L. C. F.

Mineralogical Composition of Self-Fluxing Sinters. N. G. Moleva and P. S. Kusakin. (*Stal'*, 1957, (12), 1068–1071). Phase composition depends greatly on silica content. With 12–16% SiO_2, CaO reacts to form Fe-Ca and Al-Ca silicates. Ca ferrites occur near the pores to the extent of 10–15%. With 7% SiO_2 the calcium-rich low-melting component dissolves Fe_3O_4 and, on cooling, Ca ferrites separate. Up to 30–45% were present. Limestone sinters are not strong but might be improved by slow cooling.

Automatic Control of Sinter Belts. H. Schwanzer. (*Hutník*, 1957, **7** (9), 312–313). [In Czech]. A method for the automatic control of the velocity of sinter conveyors, in which the temperature difference between the final suction boxes is utilized, is proposed.

Apparatus for Determining the Reducibility of Sinters. N. L. Gol'dshtein and N. S. Khromchenko. (*Zavods. Lab.*, 1957, **23**, (11), 1391–1392). [In Russian]. A brief account is given of apparatus and procedure for determining the reducibility (in hydrogen) of iron-ore sinter. The powdered specimen (2 g.) is subjected to the action of H_2 at 600°C for 10 min.—S. K.

Low-Cost Method Strengthens Iron Ore Pellets. (*Iron Age*, 1957, **180**, Nov. 21, 130–131). A new method for pelletizing and heat treating magnetite concentrate, developed by Allis-Chalmers Mfg. Co., is described. The stages are: forming pellets in pan or drum; drying and heating pellets on a moving grate; final firing of pellets in a rotary kiln. Fuel consumption is about 750,000 B.Th.U. per net t due to efficient heat utilization. Pilot plant trials have been made.—D. L. C. F.

FUEL PREPARATION PROPERTIES AND USES

Coal Preparation Practice. A. E. Whittle. (*Iron Coal Trades Rev.*, 1958, **176**, Jan. 24, 203–206). A review of picking, washing and flotation processes.

A Revision of the Geology and Coal Resources of the Raniganj Coalfield. D. R. S. Mehta. (*Mem. Geol. Survey India*, 1956, **84**, pp. 113).

Petrology of Indian Coals. P. N. Ganju. (*Mem. Geol. Survey India*, 1955, **83**, pp. 101).

Coal Resources of Oklahoma. J. V. A. Trumbull. (*U.S. Geol. Survey Bull.*, 1957, No. 1042–J, 307–382).

Geology and Coal Resources of the Starkville–Weston Area Las Animas County, Colorado. G. H. Wood jnr., R. B. Johnson and G. H. Dixon. (*U.S. Geol. Survey Bull.*, 1957, No. 1051, pp. 68).

Dilatometric Properties of Indian Coals. S. Sarkar, V. V. Rao, S. C. Das Gupta and N. N. Das Gupta. (*J. Sci. Ind. Res.*, 1957, **16B**, Dec., 539–547).

Experiments on the Influence of Water Content, Granulation and Addition of Oil on the Bulk Density of Coking Coal. H. Echterhoff. (*Glückauf*, 1958, **94**, Jan. 18, 110–121).

Pyrolysis of Coal and Shale. C. H. Prien. (*Ind. Eng. Chem.*, 1957, **49**, Sept. Part. II, 1548–1552). (94 references).

Opinions on the Preparation of Coking Coal. K. Lemke. (*Glückauf*, 1958, **94**, Jan. 18, 121–125).

Coking of Coal. Sovaco Plant for Selective and Petrographic Preparation. E. Burstlein. (*Techn. Mod.*, 1957, **49**, Aug., 439–443). The principles of the Burstlein-Longwy process for producing coking coal by blending are outlined and the Sovaco coking plant at Thionville, which uses this process, is briefly described. The problems facing the Italian coke producers in obtaining satisfactory metallurgical coke from American coals are also discussed.—B. C. W.

Characteristics of Coke Ovens of the Mines of the Bassin Nord—Pas de Calais. (*Echo Mines*, 1958, Jan., 11–14). An illustrated description.

Coke Ovens of Mines and Iron and Steel Works of Lorraine. (*Echo Mines*, 1958, Jan., 15–17).

Coke Ovens of Iron and Steel Works. P. Heuson. (*Echo Mines*, 1958, Jan., 19–24). A general account with a description of the ovens at S.A. Cockerill—Ougrée and at S.A. d'Espérance Longdoz. A plan and description of the Coppée battery design is added.

The Coke Industry of Belgium. (*Echo Mines*, 1958, Jan. 24–25). A brief account of installations is given.

Utilization of Weakly-caking Coals in Metallurgical Coke Production. H. Bardgett. (*Iron Coal Trades Rev.*, 1958, **176**, Feb. 7, 333–337). A review of blending, agglutinating and briquetting methods, and of the Carling, Marienau, Burstlein and Baumco processes is given, and also of the National Fuels and National Coal Board Processes.

Safe Operation of Coke Ovens. (*Iron Coal Trades Rev.*, 1958, **176**, Feb. 14, 389–391). An interlock signalling system using X-rays to ensure correct alignment of pusher and coke guide acquired by the Woodall-Duckham Co. is described.

Coking Trials on a Semi-Technical Scale. (*Glückauf*, 1958, **94**, Jan. 18, 102–110).

Effect of Wall Temperature on Coke Quality: Trials at Marienau. R. Busso. (*Centre Doc. Sidér. Circ.*, 1958, **15**, (1), 139–145).

Coking Methods and Products: Coal Carbonisation Research. J. D. Price and M. E. Mador. **Fluid Coking Development: A Mechanically Fluidized Reactor.** B. V. Molstedt and J. F. Moser jun. **Coal Desulphurization in a Fluidised Carbonizer.** J. K. Jacobs and J. D. Mirkus. **Low-Ash Graphite Prepared from Anthracite.** M. G. Boobar, C. C. Wright and C. R. Kinney. **Pitch Binder Coke Yields.** S. W. Martin and H. W. Nelson. **Microstructures of Carbon Products.** S. W. Martin and F. L. Shea jun. (*Ind. Eng. Chem.*, 1958, **50**, Jan., 17–46).

A Method of Measuring the Reactivity of Coke. A. F. Boyer. (*Centre Doc. Sidér. Circ.*, 1958, **15**, (1), 135–137).

Additions to the Study of Coke. A. Lermusiaux. (*Chim. Ind.*, 1957, **78**, Dec., 612–618). An addendum to a previous article. X-ray patterns are interpreted on the basis of a C12 unit of 2 aromatic rings and means for deducing the progress of graphitization are suggested.

Study of the Properties of Six Cokes. (*Pub. I.R.S.I.D.*, 1957, Series B, Dec., **35**, 1–116). The results of a comprehensive series of tests carried out on six cokes by 12 different organisations are reported in detail and discussed. The cokes are representative of those used in France and made in the East, North, Sarre and Ruhr districts. Thirty-two different measurements were made on the samples and these include the conventional tests. One of the main purposes of the investigation was to measure the difference between different samples and within the same sample.—B. G. B.

The Importance of the Roga Index in the Determination of the Coking Power of Coal. J. Hamaker. (*Chal. et Ind.*, 1958, **39**, Jan., 3–13).

The Microscopical Examination of Coal and Coke, Including Some Physical Tests Relating to Coking Properties. B. Moodie. (*J. S. Afr. Inst. Min. Met.*, 1598, **58**, Jan., 271–290). Microscopical examinations of coal and coke were made on a quantitative basis, and the devolatilization properties and plastic properties of the coals were studied. Constituents were classified and it was shown that enrichment by selective crushing is possible. Dedusting, in particular, should improve coke properties.

AIR POLLUTION AND SMOKE

The Air Pollution Bibliography, Vol. I. J. R. Gibson, W. E. Culver and M. E. Kurz. (*Library of Congress Tech. Inf. Division, for U.S. Public Health Service*, 1957, July, pp. 150). 750 abstracts are given for the period since 1952.

Trends in Air Pollution. W. C. L. Hemeon. (*Ind. Heat.*, 1957, **24**, Nov., 2320, 2322, 2324, 2326). A brief account of recent American work on the measurement of quantities of dusts and smoke in stack gases and on the reduction of O.H. fume.—A. D. H.

Dust and Fume Control. J. C. Somers. (*Mech. Eng.*, 1957, **79**, Nov., 1022–1024). A survey of equipment.

The Design of Collector Bells for Hot Gas and Fume Ducts. B. Berounský. (*Hutník*, 1957, **7**, (9), 310–311). [In Czech]. Certain incorrect designs leading to inefficient ventilation are pointed out.—P. F.

Simple Smoke Indicators. W. Hill. (*Fuel Econ. Rev.*, 1958, **36**, 115–117, 119–120). Boiler practice is mainly referred to on the basis of B.S. 2741 : 1957.

Dispersal of Dust Particles from Elevated Sources.—II. Limitations of the Approximate Theory. G. T. Csanady. (*Austr. J. Phys.*, 1957, **10**, Dec., 558–564).

Electron-optical Investigations on Metallurgical Dusts, Especially their Preparation and Physical Differentiation. A. M. D'Ans and L. von Bogdandy. (*Proc. Stockholm Conf. on Electron Microscopy*, 1956, Sept., 328–331). [In German]. Preparation of samples and structures observed as well as counting procedures and light extinction measurements from flames are described. Refining, basic Bessemer and Rotor process dusts are shown.

TEMPERATURE MEASUREMENT AND CONTROL

Influence of Humidity on Measurements with Radiation Pyrometers. R. Smit. (*Appl. Sci. Res.*, 1956, **5B** (6), 428–436). Calculations and experimental checks are reported. Corrections for various lens systems and detecting units are given.

Temperature Measurement and Control. (*Usine Nouv.*, 1958, Jan. (Monthly Edn.), 61, 63, 65, 67, 68). A review of apparatus including dilatation, electric and optical methods, recorders and thermostats.

REFRACTORY MATERIALS

An Introduction to Refractories. C. M. Becker. (*Inst. Brit. Found., Aust., Convention*, 1957, 15–28). The various types of refractories available to industry are reviewed and the significance of some of the tests applied to these materials is considered. Typical ways in which refractory failures occur are enumerated and discussed. The properties and uses of hot face insulation bricks are briefly described.—B. C. W.

Manufacture of Silica Products Highly Refractory under Load and of Low Porosity from Pure Iser Mountains Quartz. S. Pawlowski. (*Prace Inst. Ministerstwa Hutnictwa*, 1957, **9** (6), 241–251). The material is 99·6% SiO_2 with Al_2O_3, TiO_2 and alkali not over 0·15%. In a 70 t O.H. furnace they have a life 40% longer than conventional silica products.

Contribution to the Problem of Choice of Mortar for Silica Brick Linings. F. Stebel. (*Hutník*, 1957, **7**, (7), 241–244). [In Czech]. Some laboratory and works experiments with mortars of different compositions are reported; the alumina content was the main variable in the mortars used. Low alumina contents lead to less running of the mortar in use and to less damage to the bricks than do mortars high in alumina.—P. F.

Equilibrium Studies in the Systems: Zirconium Oxide and Calcium Oxide with Iron Oxides. W. A. Fischer and A. Hoffmann. (*Arch. Eisenhüttenwesen*, 1957, **28**, Dec., 771–776). A report is given of radiographic and microscope studies to determine the solubility limits of iron (II)-oxide and iron (III)-oxide in the calcium-oxide: zirconium-oxide: fluorspar phases.—L. J. L.

Qualitative Assessment of Diffusion and Migration of Ferric Oxide in Quartzites and Silica Products. S. Pawlowski. (*Prace Inst. Ministerstwa Hutnictwa*, 1957, **9**, (6), 253–257). A tracer study with ^{59}Fe is reported in 20 mm cube test-pieces at 1460° C in oxidizing and reducing atmospheres. Granularity, it is concluded, should not exceed 2–2·4 mm. Penetration is deeper under reducing conditions.

A Trial of the Quality of Refractory Materials in the Casting Pit and the Distribution of Non-Metallic Inclusions in Steel by means of Radioactive Tracers. Z. Bojarski, W. Orzeszko, R. Wusatowski, Z. Ziolowski and S. Pawlowski. (*Prace Inst. Ministerstwa Hutnictwa*, 1957, **9**, (6), 259–268). Labelled Fe_2O_3 was introduced into the fireclay and the steel ingots and blooms examined radiographically. Paraboloid distributions in the ingot heads were found, and in blooms inclusions were distributed about 7 mm below the surface, the thickness of the zone increasing toward the top. Runner bricks of low refractoriness gave more uniform distribution and lower mean activity than did high refractory materials.

The Slagging of Refractories by Brown Coal Ash. K. Grant. (*Austr. J. Appl. Sci.*,

1957, **8**, Dec., 323–334). All refractories tested were attacked at 1200–1400° C.

IRON AND STEEL—GENERAL

Developments in the European Steel Industries. D. J. O. Brandt. (*Iron Coal Trades Rev.*, 1958, **176**, Jan. 17, 139–145). The belt-charged blast-furnace at Liège, the Maers-Boelens O.H. furnaces with inward sloping walls, the Krupp-Renn process, Rotor plants in Germany and South Africa, the L. D. and Kaldo processes, degassing techniques, and the alloy steel resistance heating installation at Bochumer Verein are briefly surveyed, with comments on the relative backwardness of the British industry.

Present Position of the Spanish Iron and Steel Industry. (*Dyna*, 1957, **32**, Sept., 541–561). [In Spanish]. A detailed factual report of the state of the industry is given. Production, productivity, demand, prices, finance, investments and exports are discussed and the fundamental points at issue and the future needs are summarized.—P. S.

Aspects of the Italian Iron and Steel Industry. E. C. Didier. (*Usine Nouv.*, 1957, **13**, Dec. (Monthly Edn.), 1, 3, 4; 1958, **14**, Jan. (Monthly Edn.), 1, 3–5). A review of recent developments with a brief account of the Schuman Plan and of the Usines Cornigliano et Bagnoli. The old works at Bagnoli and the Falck company are then reviewed, and the Fiat-Ferriere integrated works with historical notes and brief accounts of the present installations. The future outlook is also discussed.

Expansion of the Iron and Steel Industry in São Paulo. R. N. Jafet. (*Bol.A.B.M.*, 1957, **13**, July, 171–193). [In Portuguese.] After a brief historical review and statement of the present position, the future developments and trends of various aspects of the industry are discussed in turn. These are: ore freight, scrap, electric power, operatives, electrodes, investment and finance, expansion (of individual firms), decentralization, COSIPA (the Paulista Steel Co. with an intended 1,000,000 t production to be sited at Piaçaguera), and coal and coke. The final section discusses the need for the development of São Sebastião as a rail-head, major port and possible steel-making centre: the author believes this will largely depend on foreign interests.—P. S.

Progress of Metallurgy in Europe. H. Sutton. (*Met. Prog.* 1958, **73**, Jan., 102–104). A short general review is presented.

Forty Years of Soviet Ferrous Metal Industries. P. N. Kushnir and O. S. Michajlov. (*Hutn. Listy*, 1957, 12, (11), 962–964). [In Czech]. The development of the Soviet Steel Industry since the October Revolution of 1917, is reviewed, and projects for the sixth five-year plan 1957–62 are listed. Further development and application of recent techniques, increases in the dimensions of blast-furnaces, expansion of existing plant, and the establishment of a new large ferrous industry in Siberia are envisaged, as parts of the plan.—P. F.

Thirty Years in American Metallurgy. J. J. B. Rutherford. (*Met. Prog.*, 1958, **73**, Feb., 106–111). The state of ferrous metallurgy in 1926 is reviewed and the advances made since that date are described.—B. G. B.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG-IRON

The Development of Pig-Iron Production in the Klement Gottwald Steelworks in Vitkovice. V. Lukeš. (*Hutník*, 1957, **7**, (10), 331–334). [In Czech].—P. F.

A New Design of Blast Furnace Charge Distributor. Z. Krotk'evskii (*Izvest Akad. Nauk, Otdel. Tekhn.*, 1957, (4), 40–44). [In Russian]. A description of a new type of charge distributor which can empty each skip across the whole surface of the small bell or of the large bell in a thin layer, is given. It consists of a distributing funnel placed over the small bell with one or more outlets and with an inserted screw-like scraper which rotates together with the distributing funnel. Materials placed into the distributor cannot fall immediately on to the small bell but are pushed out by the scraper throughout the rotation of the distributor over the bell (in about two revolutions).—V. G.

Getting More Iron from Blast Furnaces. (*Steel*, 1957, **141**, Dec. 9, 164–176). The National Steel Corporation's programme for increasing iron production, as described to the 25th B.I.S.R.A. Blast Furnace Conference, is outlined. Sinter plants are being built, the largest having a continuous strand 12 ft wide and 200 ft long with a capacity of 8400 t per day. The benefits of a prepared burden are reported. The effect of the coking-coal preparation (including pulverization and granulation) are explained. Several years experience of O_2-enriched blast is reviewed; three blown-out furnaces which had each made over 3×10^6 t hot metal did not show any deterioration of refractories due to the use of O_2. The balancing of O_2 enrichment and increased blast heat with moisture in the blast is described. The effect of O_2, moisture, and high top pressure on the driving and reduction rates are indicated. Planned improvements include additional stoves, orifice gas washers to ensure cleaner stoves and water-cooled carbon lined boshes.

A Method of Radiometric Probing of a Blast Furnace and Possibilities of Its Application. A. A. Melik'yan. (*Izvest, Akad. Nauk. Otdel. Tekhn.*, 1957, (4), 146–148). [In Russian]. A method of measuring rates of burden descent in blast furnaces based on the insertion of radioactive sources (^{60}Co, about 1 millcurie) at a given furnace level and at a given position along the radius, and measuring the radioactivity at a lower level with counters in a water-cooled probe which is inserted at fixed time intervals. The time elapsed between the insertion of the radioactive source and the time of registering of maximum radioactivity from this source gives the time taken for the burden at a given furnace level to fall the distance between the two levels. Some examples of measurements which were carried out in the Novo Tul'sk Works are given. Other possible applications of the method, such as measurement of the distribution of burden materials, are discussed—V. G.

A Study of the Movement of Materials in the Blast Furnace by Means of Radioactive Isotopes. I. G. Polovchenko. (*Stal'*, 1957, (12), 1057–1068). Ampoules containing tracer materials are added by the method described and counters for the tuyere and hearth are developed. The movements are shown on a diagram. The rate in the upper part of the stack is not uniform across the section and varies with time. The lowest rate is in the wall zone and the highest is often 2 ft from the wall but sometimes at the centre. Some lumps of coke or ore tend to move into the axial region; lower down movement is more intensive and coke tends to move towards the wall. After melting the ore moves more rapidly than the coke and arrives at tuyere level at ~ twice the speed. Lumps of coke circulate widely in this zone, some falls below the oxidizing zone and is returned from the molten iron to the hearth. CO_2 content is correlated with movement of the burden.—

Distribution of Titanium Between Blast-Furnace Metal and Slag. P. Mehta, and V. G. Paranjpe. (*Trans. Indian Inst. Met.*, 1956–57, **10**, 51–60). The factors affecting the distribution of Ti between metal and slag in local blast furnace practice are evaluated from operational data. The Ti content varied between 0·12 and 0·21%, the extent of reduction increasing with increasing temperature. The reduction of Ti is correlated with that of Si by the index

$$K_{Si\text{-}Ti} = \left(\frac{\%\ Ti_{metal}}{\%\ Ti_{slag}}\right) \Big/ \left(\frac{\%\ Si_{metal}}{\%\ Si_{slag}}\right)$$

The index increases with temperature and basicity and is decreased by increasing the TiO_2 content of the slag. The Mn recovery coefficient can also be correlated with the Ti content of the metal.—B. C. W.

Possibilities of Desulphurizing Blast-Furnace Hot Metal. Part I—By Additions of Aluminium Near the Iron Notch During Casting. A. Banerjee, V. G. Paranjpe and S. Visvanathan. (*Trans. Indian Inst. Met.*, 1956–57, **10**, 21–31); **Part II—By Injecting Fluidised Agents.** P. K. Chakravarty, V. G. Paranjpe and S. Visvanathan. (33–50). I—Plant trials and laboratory experiments showed that the addition of metallic Al to molten pig iron in the presence of blast furnace slag did not desulphurize the metal. Further laboratory experiments indicated that the presence of about 1·6% Si and 0·1–0·15% Ti in the local pig iron altered the metal characteristics such that Al additions did not aid desulphurization. II—The extent of the desulphurization achieved with pig iron containing 1·6% Si and 0·15% Ti when fluidizing agents were injected into the bath was determined for a number of different agents, which included mixtures and powdered slags. Of the individual agents the most effective were CaC_2, $CaCN_2$, CaSi and a selected grade of lime. The effectiveness of a lower grade of lime was markedly increased by adding fluorspar or Al. Of the slags used the best results were obtained with a basic electric arc furnace reducing slag containing about 1%CaC_2. The results obtained with CaO-MgO-SiO_2 synthetic slags are discussed in relation to their liquidus temperatures and basicity.—B. C. W.

Pre-Refining of Pig-Iron. O. Bohuš. (*Hutník*, 1957, **7**, (11), 381–384). [In Czech]. Advantages and difficulties arising from the use of pre-refining by means of O_2 in a mixer are discussed. At present the endeavour is made at the Klement Gottwald Steelworks in Vítkovice to assure uniformity of the composition of pig-iron by the use of ore sintering and homogenization rather than by means of the oxygen lance.—P. F.

Blast Furnace Blowers of Radial and Axial Type. H. Meienberg and H. Stamm. (*Escher-Wyss News*, 1957, **30**, (1), 3–14). An illustrated account with blade plans and notes on control.

Calculation of the Characteristic Curve of Blast Furnace Blowers and Other Parameters of Air Supplies. J. Sentek. (*Maschinenbau Wärme*, 1957, **12**, Dec., 333–336). Mathematical. Turbo-blowers are considered.

Trends in the Development of Blast-Furnace Blast Production. H. Haniš. (*Hutník*, 1957, **7**, (7), 217–221). [In Czech]. Various types of blast generators are reviewed. The most appropriate type depends upon local conditions both economic and technological. Gas turbines driving rotary blast generators may eventually come into universal use.—P. F.

Gas Turbines as a Direct Source of Blast for Blast Furnaces. M. A. Nechaev. (*Stal'*, 1957, (12), 1140–1141). The scheme for producing blast by means of gas turbines differs from other gas turbine installations for the combined compression and heating of blast by the direct utilization of the exhaust turbine gases containing 17 to 18% O_2 and 3 to 4% CO_2. The main advantage is the absence of an air boiler while the chief drawback is the necessity for a supplementary (10 to 15%) consumption of heat (coke) for decomposing the CO_2 in the combustion zone which is not made good by a reduction in the gas consumption for heating the blast.—B. S.

An Example of Turbo-Machines in the Steel Industry. C. Peschon. (*Rev. Tech. Luxembourg*, 1957, **49**, July–Sept., 147–169). A detailed examination is made of the efficiency of gas and steam turbines for blast furnace blowers. Particular reference is made to the gas and steam turbines installed at the Dudelange works of ARBED.—B. G. B.

Heating the Blast-Furnace Blast. M. Havelka. (*Hutník*, 1957, **7**, (11), 384–388). [In Czech]. The basic theory of blast heating is discussed and related to practice. It is shown that careful control of combustion and heat transfer processes can lead to an increase in thermal and economic efficiency.—P. F.

Thermodynamic Studies of the Desulphurisation and Dephosphorization of Iron. L. A. Shvartsman. (*Hutn. Listy*, 1957, **12**, (11), 965–970). [In Czech]. A detailed report is given of studies of the chemistry of both processes by means of radioactive isotopes. The partition coefficients of S between the

metal and an acid slag was found to be about 0·5 at 1600° C, the temperature dependence of the partition coefficient L_S being $\ln L_S = (6000/T) - 3{\cdot}56$, and that for P $\ln L_P = (15000/T) - 9{\cdot}64$. The latter is sensitive to minor concentrations of SO_3 in the slag, and to the CaO content. Several complex secondary reactions affecting both desulphurization and dephosphorization were found.

The Effect of Sulphur Concentration on the Kinetics of Desulphurization of Iron. J. Škála and O. V. Travin. (*Hutn. Listy*, 1957, **12**, (11), 1000–1008). [In Czech]. Desulphurization of iron containing 0·001–0·750% S was studied by a radioactive tracer method in the range 1410–1750° C. The activation energy of the process increases with the S concentration from 10–59 kcal/gram-atom over the above range of concentrations. With concentrations near the lower end of the range the rate of desulphurization is virtually temperature-independent. The order of the reaction changes from 0·9 at 1410° C to 1·3 at 1750° C. The rate is practically independent on the amount of slag, but is inversely proportional to the weight of metal for a given size of slag-metal interface.—P. F.

All-Welded Main Will Carry Blast Furnace Gas. (*Gas World*, 1958, **147**, Feb. 8, 310). A 10,000 ft main is described to carry gas from Cleveland to Lackenby works.

Linings for Hot Metal Mixers. F. H. McRitchie. (*Refractories Institute Tech. Bull.*, 1957, Nov., pp. 12). Factors affecting wear and the results of a questionnaire are given. Design and construction and service factors are discussed and refractory selection is considered. (29 refs.).

PROPERTIES, TREATMENT AND USE OF SLAG

Phase Equilibrium Relationships at Liquidus Temperatures in the System FeO–Fe_2O_3–Al_2O_3–SiO_2. A. Muan. (*J. Amer. Ceram. Soc.*, 1957, **40**, Dec., 420–431).

Comparison of Physico-Chemical Properties of Primary Blast-Furnace Slags with Their Mineralogical Composition. N. L. Zhilo, A. V. Rudneva and G. A. Sokolov. (*Izvest. Akad. Nauk Otdel. Tekhn.*, 1957, (6), 37–42. [In Russian]. Data on the phase composition and a comparison of the actual and calculated mineralogical compositions of primary blast-furnace slags (produced during smelting basic and foundry iron) with their physical properties, are given. The investigation was carried out in order to establish the cause of variation in the behaviour of K_2O in acid and basic slags. The comparison of viscosity, crystallization temperature and phase composition indicated that the negative influence of alkali on the physical properties of these slags is caused by the formation of high-melting alkali aluminosilicate groupings with a three-dimensional skeletal structure of anionic complexes (of the type of kaliophilite and leucite).—V. G.

An Investigation of the Viscosity of Primary Blast Furnace Slag. N. L. Zhilo, A. V. Rudneva, G. A. Sokolov and L. M. Tsylev. (*Izvest. Akad. Nauk Otdelenie Tekhn.*), 1957, (2), 27–35). [In Russian]. This investigation was carried out in order to study the influence of alkali and FeO in the presence of alkali on the viscosity of primary blast-furnace slags. The chemical compositions of natural and synthetic slags investigated are given. It was found that K_2O decreases the viscosity and the temperature of crystallization of acid as well as basic slags not containing Al_2O_3. An increase in the K_2O content in aluminous slags with 5–10% of Al_2O_3 decreases the viscosity and the temperature of crystallization only of acid blast-furnace slags and has an opposite influence on basic slags. FeO decreases the viscosity and the temperature of the beginning of crystallization. This influence is more strongly pronounced in acid slags than in basic slags. Alkali additions in amounts from 3 to 16% decrease the viscosity and the temperature of crystallization of ferrous slags with a CaO to SiO_2 ratio of from 0·61 to 1·16. Increasing CaO/SiO_2 ratio leads to a decrease in viscosity and an increase in the crystallization temperature in alkali-containing ferrous slags. The presence of alkalies in slags aids in displacing ferrous iron from slag melts, thus increasing the process of reduction of iron oxides.—V. G.

DIRECT PROCESSES

Industry Looks at Direct Reduction. J. W. Franklin. (*Eng. Min. J.*, 1957, **158**, Dec., 84–93). A review of processes in use and companies using them, with diagrammatic plans of plant and lay-out is given, with an account of the possible advantages and the conditions in which the new processes might be superior to blast-furnace installations.

New Process Reduces Iron Oxides With Carbon Monoxide. P. M. Unterweiser. (*Iron Age*, 1958, **181**, Jan. 30, 93–95). The Stelling process for making iron carbide is described. Starting with a fluidized bed of ore the three steps are, preheating and oxidation; reduction to the wüstite stage; reduction to cementite. The final reduction is effected at 1100 to 1200° F by CO at atmospheric pressure; there is no tendency at these temperatures for iron carbide to stick. The process has been tried on a 100 kg per day pilot plant, and is well suited to large scale operation. The cementite can be readily incorporated in a continuous system for the tonnage production of steel—D. L. C. P.

Direct Reduction of Iron Ore to Yield Usable Steel. *Part II.* J. Mohan, P. K. Gupte, and B. R. Nijhawan. (*Trans. Indian Inst. Met.*, 1956–57, **10**, 73–81). Experimental results are reported on the direct reduction and sintering of Sulaipat iron ore. The reduction was carried out in powdered charcoal at 1100° C. The aspects studied included the effects of binding agents and sintering cycles on the density of untreated ore and the effects of sintering cycles and different moulding techniques on the density of electromagnetically concentrated ore. Magnetically concentrated and reduced products could be hot-forged and rolled without much difficulty to give a steel with a density of 7·8 g/cc.—B. C. W.

PRODUCTION OF STEEL

Some Equipment and Instruments Used for Process Control in the Soviet Metallurgical Industry. V. Kyselovský. (*Hutník*, 1957, **7**, (10), 352–356). [In Czech].—P. F.

Chemistry in the Metallurgy of Iron and Steel. J. Chipman. (*Pennsylvania State Univ. 31st Annual Priestley Lectures*, 1957, pp. 95). Oxidation and reduction processes in steel refining and equilibria with O_2 at 1540°, oxygen in liquid iron, deoxidation with Si, V and Al are discussed and methods of measurement outlined. Applications of Henry's law and Sievert's law to gases and C in iron are treated, and the case of Cr in steel is also taken up. Slag structures and reaction kinetics are then outlined and H_2 in steel making and its determination are dealt with, including effects of vacuum degassing. The various uses of oxygen are then outlined.

Regulating the Optimum Air Supply for Combustion. W. E. Germer. (*B.W.K.*, 1958, **10**, Jan., 10–11).

The Utilisation of Fuels at an Integrated Steelworks. J. T. Davies and K. Donnan. (*Fuel Econ. Rev.*, 1958, **36**, 41–45, 47–54). The Port Talbot works is described, the dimensions of furnaces being given and future developments are forecast.

What Sort of Chimneys for Metallurgical Furnaces? O. Hendrych. (*Hutník*, 1957, **7**, (8), 276–278). [In Czech]. Economic and technological aspects of chimney construction and design are considered. Brick constructions are said to be satisfactory and comparatively cheap; steel chimneys are too expensive except for use in special circumstances. The use of ferro-concrete appears to be promising and deserves detailed study.—P. F.

Use of Oxygen in the British and European Steel Industries. D. J. O. Brandt. (*Iron Coal Trades Rev.*, 1958, **176**, Jan. 31, 263–271). A review of developments in Germany, France, Austria, Sweden and at home, with discussion of possible future advances is given.

The Development of the V. M. Molotov Steelworks in the Period of the Building of Socialism in our Republic. A. Bichler. (*Hutník*, 1957, **7**, (10), 328–331). [In Czech].

The Development of Modern Technology in the New Steelworks of the Klement Gottwald Plant in Vitkovice. O. Bohuš. (*Hutník*, 1957, **7**, (10), 334–337). [In Czech].—P. F.

The New Klement Gottwald Plant—Our Greatest Metallurgical Project in Building Socialism. V. Malý. (*Hutník*, 1957, **7**, (10), 338–340). [In Czech].—P. F.

The Ghost from the Converter. Sir Henry Bessemer in a Modern Steel Plant. T. Kootz. (*Iron Coal Trades Rev.*, 1958, **176**, Jan. 17, 159–167); from *Düsseldorfer Nachrichten*, 1957, Oct. 24). A fanciful account to the effect that essential changes in steel production since Bessemer's day have been small, and looking to the future to produce changes.

The Development of Converter Methods of Steelmaking Involving the Use of Oxygen in the U.S.S.R. F. Krumnikl and J. Bartoš. (*Hutn. Listy*, 1957, **12**, (11), 1026–1033). [In Czech]. An account is given of recent intensive researches in the Soviet Union designed mainly to produce steel of O.H. quality by converter methods. This has been achieved through the use of the oxygen-lance with the utilization of undiluted O_2 of technical purity.—P. F.

Oxygen Rejuvenates the Converter Process. E. C. Wright. (*Met. Prog.*, 1958, **73**, Jan., 65–71). The use of oxygen in steelmaking is discussed with particular reference to the L–D top blowing process and American developments. Oxygen production on a large scale and waste gas cooling and cleaning are also considered.—B. G. B.

The Linz-Donawitz Process for Making Steel of High Quality. M. Dieterle. (*Tech. Indust.*, 1957, **36**, Sept., 1117–1123). [In Spanish]. The economics and techniques of present day steel production are discussed in order to underline the possible advantages of the L-D process. Details of the L-D process are given and its value to the Argentinian industry is indicated.—P. S.

J. and L. Joins Oxygen Steelmakers. (*Steel*, 1957, **141**, Dec. 30, 62–64). The design and operation of two oxygen furnaces at Jones and Laughlin Steel Corp. are described. They will make steels low in N, P and S for pipe, tinplate, cold heading wire, welding rods and light structural applications. The vessels are charged with hot metal and scrap, tilted upright, charged with lime and roll scale from chutes, and then blown with oxygen from a water-cooled lance. Fume passes through a hood into a wet washer and electrostatic precipitator.—D. L. C. P.

Basic Open-hearth Steelmaking in the U.S.A. M. W. Lightner and D. L. McBride. (*J.I.S.I.*, 1958, **189**, July, 205–216). [This issue].

Open Hearth Instrumentation. (*A.I.S.I. Contrib. Met. Steel*, 1957, Dec., pp. 11). The results of a questionnaire are tabulated and discussed.

Prevent Lighting-Off Explosions With Safety Controls. J. B. Smith. (*Iron Age*, 1957, **180**, Nov. 7, 134–135). A new control system is described, which prevents explosion when lighting up furnaces. Only when all burner cocks are fully closed can gas or compressed air flow through a check line connected to each and the main valve be opened.—D. L. C. P.

Kreutzer Type Roofs. M. Mulsant. (*Centre Doc. Sidér. Circ.*, 1958, **5**, (1), 159–167). A review is given of the performance of silica roofs in O.H. furnaces at Mont St. Martin, France, using the Kreutzer system of construction. Details of campaign lines and brick consumption/t of steel indicate that the system has proved successful.—B. G. B.

Suspended Basic Refractory Door Jambs Minimise Front Wall Repairs in Open Hearth Furnace. (*Ind. Heat.*, 1957, **24**, Nov., 2381, 2384). The suspended portion is located above the slag line and utilizes metal cased basic refractory tiles.—A. D. H.

Plan For Long Bottom Life. R. M. Jordan. (*Steel*, 1958, **142**, Feb. 10, 86, 88, 90). A charging system to minimize wear is given.

Scrap is charged where the bottom is high and limestone where it is low.

Experimental Smelting of Steel from Charges with an Increased Proportion of Hot Metal with Application of Oxygen. M. M. Pischikov. (*Izvest. Akad. Nauk Otdel. Tekna.*, 1957, (7), 103–112). [In Russian]. Results of 13 experimental heats carried out in 185-t O.H., furnaces with charges containing 77, 84·2 and 100% of hot metal are analysed and compared with usual melting shop practice of 65% hot metal in the charge. In all experimental melts, O_2 addition to the flame similar to that in normal practice was used. With increasing proportions of hot metal in the charge when using O_2 in the flame, no decrease in the output was found. The optimum proportion of hot iron in the charge from the point of view of the duration of the heat is 77%, but even with 85% and 100% hot metal, the duration of the heat is somewhat shorter than in the usual practice with 65% of hot metal. The consumption of O_2 with increased proportion of hot iron was 35·6–45·2% higher than in the usual practice but the consumption of fuel decreased by 13·9–4·6%. The amount of slag in the experimental melts increased by 17–45% which necessitated the removal of slag through the back wall with two runners. The yield of liquid steel increased by 1·1–6·9%. The reduction % of iron from the ore increases from 40·8% with 65% of hot iron to 51·3, 61·9 and 67·7% with 77, 85 and 100% of hot iron respectively. The cost of production with a high proportion of hot iron in the charge decreases somewhat.—V. G.

Maintenance of Steelmaking Furnaces and Planning of their Repairs. J. Gargula. (*Hutnik*, 1957, **7**, (8), 266–268). [In Czech]. Organisational and economic aspects of planning O.H. furnace maintenance and repairs are discussed on the basis of statistical data from Czechoslovak steelworks collected during 1954–56.—P. F.

PRODUCTION OF FERRO-ALLOYS

The Production of Ferro-Alloys in the USSR and in Czechoslovakia. I. Petrman and E. Teplický. (*Hutn. Listy*, 1957, **12**, (11), 1050–1053). [In Slovak]. An account is given of the methods and recent developments in the manufacture of ferro-alloys in the Soviet Union, with particular reference to automatic control of alloying furnaces. Some aspects of the production of ferro-alloys and of furnaces and equipment used in their manufacture in Czechoslovakia are also considered.—P. F.

Ferro-Manganese from Lean Ore. B. R. Nijhawan. (*Met. Prog.*, 1958, **73**, Jan., 112–116). The problem of the utilization of substantial low grade manganese ore deposits in India is discussed. A number of suggested methods are considered.—B. G. B.

FOUNDRY PRACTICE

Ferrous Castings. (*Iron Age*, 1958, **181**, Feb. 13, 127–142). **Why to Consider Castings.** General advantages of casting processes are noted. **Weigh Performance and Cost in Choosing the Right Metal.** Essentially a table of the properties of grey, malleable and nodular iron and steel with notes on each and also on chilled and alloy irons and meehanite. **Design: Key to Quality, Savings.** Green sand, dry sand, floor and pit moulding, shell moulding, investment casting and permanent mould processes are reviewed with regard to their effects on design. Examples of faulty and corrected designs are shown. **Are You Preparing to Purchase?** Notes on the buying of castings are given. **Make Castings Do More Jobs.** Materials, heat treatments, welding, joining, machining and finishes are briefly surveyed.

Ferrous Castings Stretch Your Dollars. (*Steel*, 1958, **142**, Jan. 13, 70–74). Properties and uses of the following types of ferrous castings are given:—grey iron, ductile iron, standard malleable iron, pearlitic malleable iron, steel.—D. L. C. P.

Recollections of 54 Years in the Foundry Industry. C. Mann. (*Inst. Brit. Found., Aust., Convention*, 1957, 45–52). Casting techniques in use about 50 years ago are described together with some of the changes which have taken place since then in foundry practice.—B. C. W.

Design of Castings with Regard to Moulding (Part 1). A. Östberg. (*Gjuteriet*, 1957, **47**, Dec., 197–203). A report on how to design a casting in such a way as to reduce moulding costs is illustrated by examples.

Economic Efficiency, Productivity, and Lucrativeness of Operation of Foundries. H. Moehl. (*Giesserei*, 1957, **44**, Sept. 26, 602–606). The terms "economic efficiency," "productivity," and "lucrativeness" are first defined. Rationalization and mechanization are considered in terms of the economic efficiency of foundries. The capacity, production and manpower employed in West German grey cast iron foundries over the past decade is discussed. Characteristic data are tabulated. Cost analyses are given; fixed and mobile costs being considered separately. Finally performance per man and per month are discussed.—B. J. W.

The Foundry Industry in Finland. E. Autere. (*Giesserei*, 1957, **44**, Aug. 15, 4 – 490). The metal industry in Finland is first described in general terms. The supply of raw materials and energy is then considered, especially pig iron, copper, coke, petroleum, electricity, foundry sands, refractories and fluxes. The distribution and range of the foundry industry is described with particular reference to the melting processes. Some of the more important foundries in Finland are then described and illustrated with photographs.—B. J. W.

Foundries in India—Their Scope and Future. A. Vaswani. (*Inst. Brit. Found., Aust., Convention*, 1957, 37–44). The capacity and potential of the Indian foundry industry is briefly reviewed and the prospects of future developments are considered.—B. C. W.

Foundry Automation. (*Usine Nouv.*, 1958, **14**, Jan. 9, 35, 37). A general account of applications to the cupola, to sand preparation, trimming and heat treatment with the advantages obtained.

Pontiac's New Moulding Line Produces 150 Blocks an Hour. E. J. Texler. (*Foundry*, 1957, **85**, Dec., 110–113). The automated moulding line for cylinder block castings at Pontiac Motor Division of General Motors Corp., Pontiac, Mich., is described.—B. C. W.

Handling Units Speed Foundry Cycle. (*Iron Age*, 1957, **180**, Dec. 5, 134–135).

Using High-Carbon Coke for Cupola Melting. V. C. Faulkner. (*Found. Trade J.*, 1958, **104**, Feb. 27, 247). The use of imported material by the Haven Foundry Ltd., Newhaven, is briefly outlined with estimates of costs.

The Effects of Coke Size on Cupola Performance. B.C.R.A. Panel 10. (*Brit. Coke Res. Assoc., Report to Research Committee*, 1957, Sept., pp. 27). Size caused changes in performance between 2·4 in. and 3·7 in. but had no significant effect between 3·7 and 5 in. Metal temperature increased from 1379° C with 1–3 in. coke to 1425° C with 3–5 in. and above 5 in. grades. Combustion ratio also increased, fixed carbon to air ratio decreased (from 9·1 lb/1000 ft³ to 8·6 lb) as did metal to air ratio. Metal quality and analysis were not changed appreciably.

Efficient Cupola Operation. T. H. Burke. (*Foundry*, 1958, **86**, Jan., 89–93). Factors of importance in efficient cupola operation are briefly discussed. These include linings and their maintenance, bed height, tuyere design and fluxes. Tests which can be applied during operation to check melting conditions are considered together with the factors affecting chill values. In conclusion desulphurization is discussed.—B. C. W.

Some Observations on Cupola Tapping. F. D. Roper. (*Brit. Found.*, 1957, **50**, Nov., 553–556). The preparation of a cupola taphole is described together with the methods that can be used to overcome the difficulties associated in the first tapping operation with solidified iron in or behind the tap-hole. Intermittent tapping and bolting are briefly considered.—B. C. W.

The Development and Operation of the Hot-blast Cupola. E. Löbbecke. (*Giesserei*, 1957, **44**, Aug. 29, 505–515). A review article (46 references) in which the development of the cupola is traced from 1832 to the present day. The design of hot-blast cupolas is discussed and a scheme given for a completely automatic plant. Works experiences in the operation of acid hot-blast cupolas are described and contrasted with hot-blast cupolas without linings.—B. J. W.

Operating Experience with a Hot-Blast Cupola Plant. J. J. Sheehan and G. J. Shaw. (*Brit. Found.*, 1957, **50**, Nov., 556–560). The reasons for, and the plant used in, converting two cupolas to hot blast are outlined. Operating results and performance details are given and the advantages of the plant are summarized. These include the use of a cheaper metal charge to produce a better quality iron, coke and limestone savings, increased output with indirect financial savings, and reduction in scrapped castings.

Carbon Pickup in the Cupola. How to Test for Factors Affecting It. M. Perch and C. R. Russell. (*Foundry*, 1957, **85**, 70–75). A laboratory scale test for determining the solubility of cokes in molten iron is described and some results obtained using the test are given. These results show the effects on carbon pick-up of different cokes, different coke samples from the same coal blend, the ash content of the coke, the Si content of coke and metal, and additions of lime, soda-ash, and MnO_2 to the coke. Si or lime in the coke decreased carbon pick-up and soda-ash or MnO_2 increased it.—B. C. W.

Phosphorus Dilution of Iron in a Small Experimental Cupola. P. K. Gupte, S. S. Bhatnagar and B. R. Nijhawan. (*Trans. Indian Inst. Met.*, 1956–57, **10**, 61–72). The development and operation of a small (5 in. diameter) experimental cupola to work with Indian high ash cokes is described, and some results obtained on the dilution of phosphorus by using steel scrap are briefly discussed.

Oxygen Enrichment of the Air Blast for Cupola Works. (*Giesserei*, 1957, **44**, Aug. 15, 495–496). A short note in which the dependence of the melting efficiency and the temperature of the iron in a cupola on the O_2 content of the air blast is shown graphically. An arrangement is illustrated for bleeding the oxygen into the air-blast.—B. J. W.

Carbon Arc v. Induction Melting. L. J. DiNuzzo. (*Steel*, 1958, **142**, Jan. 27, 74–76). Techniques for investment casting are compared.

On Various Methods of Inoculating with Magnesium in the Production of Spheroidal Cast Irons. K. I. Vaščenko. (*Slévárenství*, 1957, **5**, (11), 324–329). [In Czech]. Several methods of injecting Mg into the cast iron are discussed; none of which is considered to provide the final answer to this problem. In all cases considered unalloyed Mg is used. Laboratory experiments suggest that the use of magnesium vapour may be most suitable, particularly from the point of view of the heat losses incurred in adding it in the solid state. The method has not yet been perfected industrially.—P. F.

Production of S. G. Iron by the Nickel-Magnesium Process. W. A. Potter. (*Brit. Found.*, 1957, **50**, Dec., 597–601). The practical aspects of the production of S.G. iron are reviewed. The aspects considered include effects of various elements, melting, methods of introducing Mg, foundry technique, and mechanical properties.—B. C. W.

Alloyed Spheroidal Cast Iron. Some Recent Applications in France. R. A. Chavy. (*Rev. Nickel*, 1957, **23**, Jan.-Mar., 13–17). The effects of alloying elements are summarized and the use of Ni–Mo–Mn castings for cams for automobiles and other machines, pump impellers of austenitic Ni steels and other parts are shown.

Pearlitic Malleable Cast Iron. M. Tilley. (*Inst. Brit. Found., Aust., Convention*, 1957, 1–13). The structure and heat-treatment of unalloyed and alloyed pearlitic malleable cast iron is reviewed and typical data are given for mechanical properties, hardenability and impact strength.—B. C. W.

The Melting of Unalloyed Steel for Casting in the Low-frequency Induction Crucible Furnace. H. Rohn. (*Giesserei*, 1957, **44**, Oct. 24, 662–665). A comparison is made between conventional melting units and the low-frequency induction crucible furnace from the metallurgical and economic points of view. Experiences in the operation of a 6-t low frequency crucible furnace and of a plant having three 1·5-t furnaces are described. Values for the chemical analyses, mechanical properties and efficiencies of a number of melts are clearly tabulated.

Metallurgical Aspects of the Choice of Steels for Pressure Casting Dies. H. Briefs. (*Giesserei*, 1957, **44**, Sep. 26, 588–593). Hardenable hot-working steels are first classified according to their performance and their alloy content. The development of die steels and the present position is reviewed. A comparison is made between air-hardening Cr–Mo-steels and 5% W-steels regarding their behaviour in tempering, in the tensile test at elevated temperatures and in their time-dependent elongation (up to 250 h). The possibilities of increasing the efficiency of dies made of conventional steels is discussed and further developments considered.—B. J. W.

D-Moulds Make Precise Steel Castings. (*Steel*, 1957, **141**, Nov. 11, 110–113). The Dietert Process for making close-tolerance carbon and low alloy steel castings with fine surfaces is described. Conventional core-blowing machines are used. The mould is blown between the pattern and a contoured metal dryer or machined blow plate. The dryer forms the back of the mould and provides the support it needs in the green state. Examples of its use as a production method are given.—D. L. C. F.

Moulding Characteristics of Hardwar Sand. B. V. Somayajulu and B. R. Nijhawan. (*J. Sci. Ind. Res.*, 1957, **16A**, Dec., 566–570). Additions of 5% bentonite rendered the sand capable of use for simple castings but the sand is not considered suitable for steel foundry use.

Control of Moulding Sands. J. M. Palacios Reparaz. (*Dyna*, 1957, **32**, Nov., 668–699). [In Spanish]. The properties required of moulding sands are reviewed, and details are given of the equipment required for sand testing together with a description of the testing techniques. Factors influencing the choice of sands are discussed and sands for steel, grey and malleable irons, and non-ferrous metals are described. Routine daily testing control is recommended and a programme is suggested. Finally, the influence of the sand's characteristics upon casting defects is briefly described.—P. S.

Application of Quality Control to a Moulding-Sand System. L. A. Deaville. (*Foundry Trade J.*, 1958, **104**, Jan. 9, 33–36). Development of the control system and the benefits resulting are set out.

Pattern Making Machinery. C. Sleeman. (*Inst. Brit. Found., Aust., Convention*, 1957, 53–60). Wood- and metal-working equipment for precision pattern making is described with particular reference to the pattern milling machine.—B. C. W.

Pattern Details in Cast Iron. "Jacques." (*Foundry Trade J.*, 1958, **104**, Jan. 9, 39–41). Use of metal inserts is described.

Practical Suggestions for the Application of Pouring Gates of Exothermic Material in the Steel Foundry. K. Reimann. (*Giesserei*, 1957, **44**, Sept. 12, 550–552). Several examples of the design of exothermic gates are illustrated. Cost savings obtainable by the use of exothermic gates are described at some length. The yield and steel saving for six different types of casting, by normal and exothermic risers are compared and tabulated.—B. J. W.

Calculation of the Cross-Section of Risers on Sand-Castings. R. Namur. (*Giesserei*, 1957, **44**, Oct. 24, 665–671). The calculation of the cross-section of risers for sand castings is considered theoretically for four different cases. An investigation to determine the ratio of the different quantities (dimensions) involved is described. The application of the theory to practice is considered, in particular, for various different designs of riser. Finally, a general case is briefly considered.—B. J. W.

Experiments on the Effect of Atmospheric Pressure on Top Feeding Heads. A. Pearson. (*Brit. Found.*, 1957, **50**, Dec., 601–604). A description is given of the results of some experiments on the use of cores to introduce atmospheric pressure to top feeding heads. When atmospheric pressure is applied the shrinkage is more compact and finishes higher in the head, particularly when the head freezes over before the insulation is applied. Furthermore an atmospheric core in the head neutralizes the effect of hot spots in the casting. It was found that a head will feed a section slightly larger than itself only if a breaker core is used.—B. C. W.

The Chilling and Densening of Cast Iron. (*Bradley's Mag.*, 1957, Winter, 3–4). Effects of Si, C, S and Mn on chill are noted and also of cooling rate and casting temperature. Densening is outlined.

A Review of Blow Squeeze Moulding. W. A. Gibson. (*Inst. Brit. Found., Aust., Convention*, 1957, 61–66). The development of the blow squeeze method of moulding is outlined and a description is given of a typical mechanized moulding unit employing the principle. The advantages of the process are summarized.—B. C. W.

Moulding Sand Compaction and Moulding Machines. (*Castings*, 1957, **3**, Nov., 21). From the B.S.C.R.A. Annual Report, a laboratory study.

The CO_2 Process and the Reasons Why. A. Kirkham. (*Inst. Brit. Found., Aust., Convention*, 1957, 29–36). The moulding of a number of castings in the author's foundry using the CO_2 process is described, and the advantages and disadvantages of the process are summarized.—B. C. W.

The CO_2 Process for Preparing Moulds. J. Melkert, D. Wemes and G. J. Peters. (*Metalen*, 1957, **23**, Dec. 15, 487–490, Dec. 31, 509–511). [In Dutch]. This is a report of a discussion which took place during a Sand Session of the Dutch Assn. of Foundry Technicians of the paper by H. G. Leverlink on this subject appearing in *Metalen* Oct. 31 and Nov. 15. The authors cited describe their experiences with CO_2 as the hardener and waterglass as the binder in moulding sands, emphasizing advantages such as less need for stoving, greater accuracy of casting dimensions, speedier and cheaper production, less transport required in the foundry, easier tamping, etc. Numerous illustrations appear in the text showing suitable methods of preparing the moulds and of the castings produced from the latter.—F. R. H.

Controlling the CO_2 Process. F. L. Turk, J. J. Gutwald, and R. P. Lanz. (*Foundry*, 1958, **86**, Jan., 94–97). The results are described of a development programme concerned with difficulties that arose in applying the CO_2 process to the production of certain cores.—B. C. W.

The Manufacture of a 340,000 Pound Alloy Steel Casting. H. E. Klugh. (*Castings*, 1957, **3**, Nov., 12–13, 15–16). Casting of a hot mill housing is described.

The Al-Fin Composite Casting Process. E. Bertram. (*Giesserei*, 1957, **44**, Sept. 26, 593–602). This process was developed in order to have Al cooling fins on a cast steel cylinder. The properties of the bonding layer between the Al and the steel (the "Al-fin" layer) are discussed, especially the metallographic structure and the thermal properties. A number of examples of the application of this process are described in this amply illustrated article (32 photographs). These include cylinders and cylinder heads for internal combustion engines, brake drums, turbine blades and various tube systems for combustion distribution heads.—B. J. W.

The CO_2 Hardening of Cement Sand Moulds and Cores. (*Metaalinstituut TNO Publ. No.* 46, 1956, Oct., pp. 7). **Part I—The Hardening Process.** H. G. Levelink. **II—Practical Application of Tube Feeding CO_2.** J. P. G. Bruschke. **III—Practical Application of Tube Feeding CO_2 through the Core Centre.** L. A. Roos. Laboratory tests showed that rapid hardening of cement sand occurs when it is treated with CO_2 so that after 5 min it attains sufficient strengths in cores to permit removal of the core box parts, and in some instances even transportation of the cores themselves. However, the sand should be allowed to harden further in the normal way. Parts II and III deal with the practical application of CO_2 treatment of cement sand and the feasibility of continuous production of heavy cores.

From Specialisation via the Production of Box-less CO_2-Waterglass Moulds to Mechanisation. K. Haake. (*Giessereitechn.*, 1957, **3**, Sept., 193–197). An account is given of the application of mechanization to the production of CO_2-waterglass moulds at the Fürstenwalde Steel Foundry (Eastern Germany) and of the results obtained. Production increased by 38% in five years.—L. J. L.

Some Swedish Experiences of the Carbon Dioxide Method. E. Gladh and K. Nilsson. (*Gjuteriet*, 1957, **47**, Oct., 166–168). The two speakers were from Asea in Västerås and Volvo in Skövde. The former gave accounts of experiments with waterglass and sand and initial production by the CO_2 method. The latter stated that the use of the method is limited at the Penta Works, but dealt briefly with all important aspects.

Founding Sands Bonded with Sodium Silicate and CO_2. V. Lo Re. (*Bol. Assoc. Brasil Met.*, 1957, **13**, Apr., 129–137). [In Portuguese]. Tests have been made of the influence of humidity, mixing time, proportion of sodium silicate, and time of application of CO_2 upon the characteristics of São Vicente beach sand. With increasing humidity, permeability remains constant, but hardness and strength decrease, the mixing time affects hardness more than strength, variation in sodium silicate content allows variations in strength and hardness requirements to be met. Knock-out can be facilitated by the addition of 0·5 to 1% asphalt. The process is economic; each job should be studied as to the best method of applying the CO_2.—P. S.

The Metering of Gas in the CO_2 Process. R. Cattaneo. (*Fonderia*, 1957, **6**, Aug., 341–343). [In Italian]. The chemistry of the CO_2 process is discussed in some detail and the need for careful metering of the gas is stressed.

New Process Speeds Semi-Precision Moulding. (*Can. Metalw.*, 1957, **20**, Oct., 42). A modified CO_2 process is outlined hardening moulds in 15–30 sec. The precision is equivalent to the shell process.

The Possibilities of Moulding by the Taccone Process. M. Lepère. (*Fonderie Belge*, 1957, July-Aug., 159–163). A description is given of the Taccone process in which a flexible membrane and air pressure are used to apply a uniform pressure to the sand in a mould. The advantages and applications of the process are then discussed.—B. C. W.

Vibration Can Improve Casting Quality. A. H. Freedman, J. F. Wallace, and F. A. Carbonaro. (*Foundry*, 1957, **85**, Nov., 98–101). Refining of grain size and improvement of mechanical properties in steel and nonferrous ingots are discussed. The effect of 60-cycle vibration on a W–Mo tool steel is shown.

Some Aspects of the Production Technology of Piston Rings. J. Bradík. (*Slévárenství*, 1957, **5**, (7), 202–208). [In Czech]. On the basis of existing work and his own researches the author concludes that gases in piston rings originate primarily in the mould, and that risers have little influence on the structure of the rings. A relation between the composition of the cast iron, expressed as carbon equivalent, and the modulus of elasticity is advanced, and a nomogram for the rapid evaluation of the composition of the most suitable cast iron for rings 0·04–0·6 in. thick is given.—P. F.

Metallurgical Factors Affecting Locomotive Castings. W. Montgomery. (*Brit. Found.*, 1957, **50**, Oct., 493–503). Typical castings are shown and methods described. Non-destructive testing methods are outlined and wear properties of brake shoes and cylinder liners mentioned and a preferred composition for the latter indicated. Reclamation by welding is discussed and a self-hardening core oil and its uses are given.

3 Steps to Profitable Use of Moulding Machines. J. M. Leaman and D. C. Ekey. (*Mod. Castings*, 1957, **32**, Nov., 41–48). The mechanisms of machines, their correct choice for the type of casting and their position in foundry lay-out are discussed.

Improvement in the Technology of Casting Cast Iron Pistons. P. A. Karkhanin. (*Liteinoe Proizvodstvo*, 1957, (5), 12–14). [In Russian]. The results based on production figures since 1948 have shown that with an increase in the Cr and Ni content in the cast iron, various casting flaws such as gas blisters, non-metallic inclusions etc. were greatly reduced, resulting also in a considerable reduction in the number of rejects. The life of the moulds greatly increased as also did the productivity.—L. H.

New Process Used at New Investment Casting Foundry. E. Bremer. (*Foundry*, 1957, **85**, Oct., 94–99). An account of the Misco Precision Casting Co. of Detroit making vanes for jet engines and similar parts is given. Mould making, melting and finishing departments are shown and described.

New Car Wheel Foundry Casts in Graphite Moulds. W. G. Gude. (*Foundry*, 1957, **85**, Oct., 110–115). Cast steel wheels for railway goods wagons are made by pneumatic forcing of metal into permanent graphite moulds from the bottom, thus avoiding erosion. The plant and processes are illustrated and described.

Metallurgical Problems in the Centrifugal Casting of Tubes. I. B. Khazan. (*Lit. Proizv.*, 1957, (4), 1–4). [In Russian]. This article is based on work carried out at the Moscow tube-casting works on the centrifugal production of high-quality cast iron tubes 100 mm in diameter, 2 m long and with wall-thickness of 4·5 mm. It deals mainly with the effects of chemical composition. Optimal silicon content was found to be 3·2–3·5%, that of carbon being 3·0–3·4% for drain and 2·6–3·0% for rising pipes. The optimal Mn, S, and Ti contents were found to be 1·1–1·2; $<0·1$ (preferably $<0·06$) 0·15; and $<0·15$–0·20%, respectively. Cr was found to be undesirable unless accompanied by Ni. Better tubes were obtained by superheating the iron to 1400–1420° C when melting a charge containing coke equal to 16–18% of the metal weight.—S. K.

Centrifugal Casting of Two-Flanged Cast Iron Pipes. M. M. Levin and V. M. Krapukhin. (*Lit. Proizv.*, 1957, **3**, (6), 1–4). [In Russian]. A full description is given for the casting of 3000 mm long tubes of 100 mm diameter for condensers. Full indications are given as to the optimum conditions of the operation, speed, etc.—L. H.

Centrifugal Casting of 2 in. Iron Stand Pipes. B. D. Khakhalin and A. N. Smolyakov. (*Metallurg*, 1957, (3), 25–27). After comparing several types of centrifugal casting processes for the production of iron tubes, the method of casting in sand-lined moulds was selected. It is compared with the use of chill moulds. The process as carried out at Makayevka in the Donbass is described.—R. S.

The Maprodent Process of Precision Casting and Its Application in the Aeronautical Industries. P. Lefranc. (*Technique Moderne*, 1955, **47**, Sept., 390–392). A system using deformable moulds in which the investment patterns are produced by injection is described. Stainless steels are cast in this way.

The Mechanism of the Production of Castings from Meltable Patterns. A. V. Baranov, V. N. Ivanov, and N. M. Osokin. (*Giessereitechn.*, 1955, **1**, Oct., 181–189; *Liteinoe Proizv.*, 1955, (6), 9–15). The lost-wax process as practised in the U.S.S.R. is briefly described, equipment and plant design for precision casting are discussed and examples are given.—L. J. L.

Casting Jaws for Stone Crushers. P. I. Ulitenko. (*Lit. Proizv.*, 1957, (4), 25–26). [In Russian]. The chemical composition of alloy cast iron for crusher jaws is discussed and data on the casting technology, microstructure and service performance of the castings are given.

Selection of the Composition of Cast Iron and the Search for a Rational Technology for the Casting of Grinding Bodies. O. A. Nesvizhskii. (*Lit. Proizv.*, 1957, (3), 1–4). [In Russian]. The work described was carried out to find a suitable composition for wear-resisting cast iron to be used instead of steel for the manufacture of balls etc. for grinding mills, a suitable casting technology and design of centrifugal machine. White non-alloyed cast iron (2·6–3·0% C, 0·6–1·0% Si, 0·6–0·8% Mn, up to 0·14% S, up to 0·25% P, and traces of Cr and Ni) produced by a duplex cupola side-blown converter process was chosen. Casting, in loam moulds, in chill moulds and by the vibration and centrifugal methods was tried, the latter being adopted. The centrifugal machine developed is described.—S. K.

Production of Large Cast-Iron Machine-Tool Castings with Forced Air Cooling of Moulds. I. V. Mitichev. (*Lit. Proizv.*, 1957, (9), 11–16). [In Russian]. The successful application of forced air cooling of pit moulds used for large castings is described. The more rapid cooling obtained leads to higher production rates, and lower costs. Castings quality is also improved.

Shell Moulding. (*Usine Nouvelle*, 1957, Oct. Edn. Mensuel, 53–61; Nov. Edn. Mensuel, 23, 25, 27, 28). A review of the process, with a short historical introduction, an account of sands, resins and the preparation of mixtures, patterns, lubrication and the casting process is given. Shell-moulding machines are then surveyed, cores, suitable alloys, and uses; and a summary of the value of the method is given.

The Manufacture and Use of Resin-Coated Sand for the Shell-Moulding Process. A. Woods. (*Fond. Belge*, 1957, Nov., 269–273). The author discusses the reason for the coating of sands with resins and compares the economic and technical advantages of the hot and cold processes of coating. These two methods are described.—R. P.

Automated Production of Shell Moulds. J. Březina. (*Slévárenství*, 1957, **5**, (8), 232–236). [In Czech]. A machine making, stoving, and hardening complex shell moulds in a nine-min cycle is described. The machine, made in Czechoslovakia, performs most satisfactorily in full-scale production.—P. F.

The Production of Low-Carbon Steel Castings by Shell Moulding. J. M. Navarro and H. F. Taylor. (*Inst., Hierro Acero*, 1957, **10**, July-Sept., 253–277). [In Spanish]. A study of the influence of variations in casting, feeding, and mould materials upon the surface quality of castings (0·18–0·22% C, 0·3–0·5% Si, 0·6–0·7% Mn) is reported. Many photographs of the actual castings made are included. Changes in the in-gate systems, position of feeders, and pouring speeds can reduce but not completely eliminate surface defects. Chemical additions to the mould, such as carbonates of Na, Ca, and Mg improve surface quality in sections smaller than 1·25 cm. Thicker castings can only be produced satisfactorily by using zircon or forsterite moulds. The possibility of producing defect-free thick castings by means of moulds prepared by blowing a mixture of sand, water and sodium silicate on to a hot pattern is demonstrated.—P. S.

Some Technical Aspects of Shell Moulding: Possibilities of Hollow Cores. A. Woods. (*Fonderie Belge*, 1957, July-Aug., 165–173, 202). Practical problems in the design of pattern plates, the cracking of shell moulds, and the choice of methods of joining half shell moulds are discussed. The manufacture, use and advantages of shell cores are then considered.—B. C. W.

Precision Toolmaking Aids Shell-Moulding. O. W. Winter. (*Metalw. Prod.*, 1957, **101**, Nov. 29, 2133–2137).

Stainless and Heat-Resistant Investment Castings. R. Taylor. (*Found. T.J.*, 1957, **103**, Oct. 24, 483–494). A brief historical survey is followed by accounts of methods used. Procedure used by Firth-Vickers Stainless Steels Ltd. is described in some detail.

Casting-to-Mould Heat Transfer. L. Petriela. (*Slévárenství*, 1957, **5**, (6), 93–100). [In Czech]. The heat transfer from metal to mould was studied with cylindrical steel and grey cast-iron ingots of 2·9–9 in. dia. cast into chemically hardened sand, ordinary natural foundry sand, bentonite sand, and fire-clay moulds. The cooling curves were obtained by means of systems of thermocouples embedded in the moulds. The irreversible dehydration of the clay binder was investigated.—P. F.

The Cooling of a Plate Casting in a Sand Mould. O. Yu. Kotsyubinskii. (*Lit. Proizv.*, 1957, (3), 9–14). [In Russian]. All stages in the cooling of an infinite plate casting in a dry sand mould are considered. The stages are grouped into two periods: solidification and cooling after solidification. The following assumptions are made in the work: (1) the thermal properties of the mould and casting are constant and independent of temperature, but the properties of liquid and solid metal differ; (2) filling time is short and can be ignored in cooling calculations; (3) the alloy has a constant temperature of crystallization; (4) the casting and mould surfaces remain in close contact; (5) excess temperature of the mould and casting are reckoned from the initial mould temperature. Because of symmetry only half the plate thickness and the corresponding mould portion have been dealt with.—S. K.

Control of Cooling of Steel Castings by Means of Chills. S. Šimoník, M. Bednářík, and J. Klaban. (*Slévárenství*, 1957, **5**, (8), 9–14). [In Czech]. Experiments on the cooling efficiency of steel and cast-iron chills of various thicknesses were carried out with steel and cast iron ingots. The effectiveness was measured as the ratio of the height of the metal zone solidified above the chill to that solidified next to the mould, at the instant of complete solidification. The boundaries of the zones were located metallographically after sectioning of the castings. The results are generalized by means of simple equations.—P. F.

A New Method of Chilling the Surfaces of Castings in the Mould. E. Knipp. (*Giesserei*, 1957, **44**, Aug. 1, 467–469). The usual method of chill-casting using permanent chill moulds is first described. The mechanism of hot crack formation and burr formation is discussed. The avoidance of crack formation on the surface of castings can be effected by the new method of chilling described. In this the chilling is carried out by a heavy link chain built into the surface of the core. The advantages of the method are extolled and examples of its application given.—R. J. W.

Measurement of Casting Surface Roughness. C. H. Good and C. E. McQuiston. (*Foundry*, 1957, **85**, Oct., 116–120). A review of concepts, definitions, apparatus, and classifications is given.

Casting Strain and Fracture Risk. W. Göschel. (*Giessereitechn.*, 1957, **3**, Sept., 207–211). It is pointed out that a casting with equal wall thickness throughout may be subjected to more strain than a casting having widely different cross-sections. Practical hints and examples are given to enable moulders to forecast strains likely to arise from the design of the casting.—L. J. L.

Surface Defects of Malleable Iron Castings. Z. Hostinsky. (*Slévárenství*, 1957, **5**, (10), 297–300). A lecture on defects produced in oxidizing and neutral atmospheres. Surface defects produced during malleablizing are discussed and theories of the pearlitic surface layers are further dealt with.

Surface Defects in Steel Castings. F. Brunn. (*Giessereitechn.*, 1957, **3**, Aug., 172–173). Surface imperfections are described, and attributed to the use of materials having excessively low softening and melting points. A hypothesis is put forward to account for the formation of dendrites in the circumstances described.

Hidden Defects in Castings. J. Přibyl. (*Sborník Vědeckých Prací Vysoké Školy Báňské v Ostravě*, 1957, **3**, (1), 47–67). [In Czech]. Bubbles, tears, shrinkage voids, desegregation, and other hidden defects are classified, the physics of their formation is discussed, and the most appropriate methods for preventing or minimizing their occurrence are indicated and theoretically justified.—P. F.

The Automatic "Bührer" Moulding and Casting Plant in the Malleable Iron Foundry at the Georg Fischer AG at Schaffhausen. W. Götz. (*Giesserei*, 1957, **44**, Sept. 26, 564–579). The recent installation of an automatic moulding and casting plant for making malleable iron castings is described. The various stages in the preparation of the moulds are described in detail, together with the placing of them on the conveyor system. The casting operation is then described and the manner in which the casting is removed

from the mould. The pattern board, mould boxes and conveyor system are all carefully described. The mode of reconditioning the facing and back-up sands are described and a measure of the efficiency calculated.

Continuous Casting of Grey Iron. A. Wittmoser. (*Met. Prog.*, 1958, **73**, Jan., 83–87). An illustrated description of the Eisenwerke Gelsenkirchen foundry in West Germany is given. This foundry produces gas and water pipes up to 3ft dia. and 33 ft long. Cylinder liners are also cast continuously. A short description of development work is also given.—B. G. B.

Investment Casting Offers Design Freedom, Economy for Host of Industries. E. C. Thys and T. N. Thys. (*Western Metalw.*, 1958, Jan., **16**, 49–51). The article describes a 14,000 ft² plant for the streamlined production of alloy investment castings as thin as 0·030 in.—B. S.

Lost Wax Process. (*Ind. Fin.*, 1958, **10**, Jan., 27). Practice at Hadfields in the casting of stainless steel is described.

Mathematical-Statistical Investigation on the Question of the Dependence of the Life of Permanent Moulds for Centrifugal Casting on the Casting Cycle. H. Bühler and W. Schreiber. (*Giesserei, Tech. Wiss.*, 1957, (17), July, 889–895). On the basis of a numerical investigation, optimum conditions for the casting cycle were established in order to obtain the maximum life for permanent moulds for centrifugal casting. Statistical techniques were employed to utilize data from the Works. The effect of cooling the permanent moulds on their life is discussed.

Mould-Metal Interface Reactions. H. F. Taylor and J. Navarro. (*Foundry*, 1957, **85**, Dec., 76–80). The various ways in which a mould and the molten metal can interact are summarized and possible chemical reactions between metal, metal oxides and the refractory oxides in the moulding material are discussed together with the factors that will promote or retard these reactions. Results obtained on steel castings are briefly considered in relation to the proposed theory.

Directional Solidification in Castings. L. M. Hogan. (*Austral. Eng.*, 1957, **50**, Sept. 9, 64–69). An examination of shrinkage porosity is reported in which shrinkage in the liquid, solidifying, and solid states is discussed. Pure metals, continuous casting, solidification processes, and applications in ingot and sand castings in which directional effects are noted are discussed. Examples are drawn from non-ferrous systems.

The Development of Internal Stresses during the Casting of Cylinder Heads. K. Bandow and C. W. Fabry. (*Giesserei*, 1957, **44**, Sept. 26, 579–582). The theoretical basis for carrying out measurements of internal stresses on castings are first described. The carrying out of these measurements on cylinder heads of Diesel motors is described and the results given. The influence of the shape of the cylinder head on the magnitude of the internal stresses is described and suggestions made for reducing these stresses.—B. J. W.

Homogeneity of Very Heavy Ingots and Its Effect on Mechanical Properties. O. Bohuš. (*Hutn. Listy*, 1957, **12**, (11), 1039–1045). [In Czech]. An analysis was made of the distribution of values of mechanical properties and of segregation and variations in composition over a central vertical section through an 80-t ingot of a basic 0·4%C steel. Some inferences concerning correct casting technology are discussed.—P. F.

An Improved Technique for Determining the Porosity of Cast Specimens. R. W. Ruddle. (*Brit. Found.*, 1957, **50**, Dec., 605–615). A method based on weighing in air and water is described for rapid and accurate porosity determinations in cast metals. The apparatus is described in detail and the testing procedure and method of computing the results are given. Two appendices give details of the methods used in the calculation, and a discussion of the accuracy required in the weighings.—D. C. W.

Investigations on the Surface Hardenability of Different Types of Cast Iron. H. Schiffers, D. Ammann and E. Brugger. (*Giesserei*, 1957, **44**, Sept. 26, 583–588). The apparatus for carrying out the Jominy test to determine surface hardenability is described and illustrated. Investigations on unalloyed and low-alloy cast irons are described, full details being given for the composition of each specimen. The two methods of heating the specimens prior to quenching, to wit, furnace heating and burner heating, are compared. The effect of alloying elements on the depth of hardness penetration is investigated by the Rockwell method. Finally causes of surface defects are discussed.—B. J. W.

Improvements in Surface Finish, Inspection, and Fettling of Grey-iron Castings. L. Clarke. (*Brit. Found.*, 1957, **50**, Nov., 539–551). The factors affecting the surface finish of castings are discussed together with the type of surface required for various industrial finishes. The organization of an inspection department is considered and aids to final inspection are described. In conclusion, methods of reducing the amount of fettling are dealt with.—B. C. W.

Air Conditioning in a Foundry. A. Riggi. (*Fond. Ital.*, 1957, **6**, Oct., 381–392). [In Italian]. This paper gives a detailed description of the air-conditioning circuits in one of the large FIAT foundries in Turin. Qualitative and quantitative data are given on ventilation and dust control. (21 References).

VACUUM METALLURGY

Vacuum Metallurgy. R. C. Bertossa. (*Mech. Eng.*, 1957, **79**, Nov., 1039–1041). Vacuum cladding and brazing are reviewed with special reference to the newer metals.

The Use of Vacua in the Steel Industry. J. Skála and D. Tlustá. (*Hutník*, 1957, **7**, (9), 290–294). [In Czech]. Advantages of vacuum casting and degassing, particularly in the production of transformer steel are discussed. Recent methods of vacuum casting and degassing, mainly as used in Germany and the Soviet Union, are surveyed.

A Critique of Vacuum Methods. (*Steel*, 1958, **142**, Jan. 13, 79–84). The roles of stream degassing, induction melting and consumable electrode arc melting are surveyed.—D. L. C. F.

Special Techniques in Vacuum Metallurgy. M. Rivera. (*Met. Treating*, 1957, **8**, Nov.–Dec., 4–7, 46; 1958, **9**, Jan.–Feb., 8–11). A review of sintering, annealing and brazing, and a survey of furnaces, pumping systems, and other apparatus with an account of heating element materials. High frequency, arc, and vacuum brazing furnaces and their control are then reviewed.

Vacuum Stream Degassing Takes Hold. K. C. Taylor. (*Steel*, 1957, **141**, Dec. 23, 70–72). The principles, practice, applications and advantages of vacuum stream degassing are described. Hydrogen contents of below 1·5 p.p.m. can be obtained on ingots up to 250 t. The method is considerably cheaper than vacuum methods for induction melting and consumable electrode melting.—D. L. C. F.

Vacuum Metallurgy. Deoxidation and Desulphurisation *in vacuo*. G. A. Garnyk and A. M. Samarin. (*Izvest. Akad. Nauk. Otdel. Tekhn.*, 1957, (5), 77–84). [In Russian]. The influence of a vacuum on the decarburization and desulphurization processes during the smelting of transformer steel in vacuum induction furnaces was studied. A laboratory furnace of 20 kg capacity and a magnesite crucible were used for the experimental melts. It was found that on smelting transformer steel in vacuum induction furnaces it is beneficial to carry out melting of the charge in open furnaces with some addition of ore. The metal should be retained under slag for some time in order to desulphurize and dephosphorize it and then Fe–Si should be added *in vacuo*. Under normal smelting conditions, a decrease in pressure to 1 mm increases the deoxidizing ability of carbon nearly one hundred times. The rate of purification of liquid metal from O_2 *in vacuo* is a few times higher than that of the decarburization process. The rate of deoxidation and decarburization *in vacuo* depend not only on the initial concentrations of C and O_2 in the metal but also on the furnace capacity.

Desulphurization of Pig Iron *in vacuo*. A. M. Samarin and I. Kaášk. (*Hutn. Listy*, 1957, **12**, (11), 970–974). [In Czech]. A study of desulphurization carried out in the laboratory in a vacuum furnace of special design showed that, (*a*) the evaporation obeys an equation of a first order reaction, so that the velocity of evaporation appears to be limited only by the rate of diffusion of S in the metal, (*b*) the evaporation is continuous within the range studied (0·008–1·03%), but slows down with time, and (*c*) is enhanced by Si, C and Al, while (*d*) dissolves oxygen tends to retard it.

The Importance of Vacuum Casting in the Steel Industry. Z. Eminger, F. Kinsky and Z. Kletečka. (*Czech. Heavy Ind.*, 1957, (2), 3–20). Ingot structures are shown in micrographs and diagrams and many studies of the distribution of elements throughout the sample are tabulated.

Heating by Induction under Vacuum. A. Bussard. (*Mét. Constr. Mécan.*, 1956, **88**, Oct., 847–851). A short review of vacuum melting equipment and its application is presented.—B. G. B.

Induction Vacuum Melting. W. E. Jones. (*Ind. Heat*, 1957, **24**, Nov., 2256–2258, 2260, 2262, 2264, 2413–2414). The operation of a 1000 lb. melting furnace is described with reference to a melt of G.E. alloy J 1300 Ni–Cr–Mo–W–Ti creep-resistant steel. The importance of maintaining low leak rates during operation to obtain better creep properties is emphasized.—A. D. H.

REHEATING FURNACES AND SOAKING PITS

Resistor-Type Heating Furnaces. Electric Soaking Pits and Other Types of Furnaces. R. Courdille. (*Centre Doc. Sidér. Circ.*, 1958, **5**, (1), 169–186). A detailed review is presented of electric furnaces for heating steel ingots and slabs. A number of commercial furnaces are first described and then performance data and calculations of energy requirements are discussed.—B. G. B.

Modernisation in Heating for Hot Forming. P. W. Morse (*Met. Prog.*, 1958, **73**, Feb., 85–90). The application of induction heating of billets prior to forging is reviewed. Automatic equipment for a variety of parts is described.—B. G. B.

HEAT TREATMENT AND HEAT TREATMENT FURNACES

The Vocabulary of Heat Treatment. E. R. Morton. (*Met. Treatment*, 1957, **24**, Dec., 481–490). Heat treatment of steel is reviewed on the basis of the equilibrium diagram and specialized curves of transformations and phase formation. Slow and rapid cooling, tempering, and the use and limitations of the transformation diagram are discussed. Structures are also considered and their relation to physical properties. Notes are added on the ordinary commercial heat treatments, martempering, austempering and the like.

Automated Continuous Roller Hearth Furnace Designed for Maximum Heat Treating Flexibility. (*Ind. Heating*, 1958, **25**, Jan., 74). A furnace built by the Industrial Heating Dept. of General Electric for annealing stator stampings and welds for electric motors is described.

Recent Improvements of Horizontal Furnaces for Heat Treatment with Electric Heating. F. Barbas. (*Usine Nouv.*, 1958, Jan., (Monthly Edn.), 69, 71, 73, 75). A review of resistors, refractories, controlled atmospheres, and various measures of efficiency is given.

Processing 310 Minimizes Carbides. H. Brown. (*Steel*, 1958, **142**, Jan. 27, 72–73). Effects of heat treatment on 310 stainless steel are tabulated and structures are shown.

Electric Furnace Economics. A. E. Pickles. (*Fuel Econ. Rev.*, 1958, **36**, 61–65). Both ferrous and non-ferrous installations are discussed and power consumption, control, layout and costs are reviewed.

Salt Bath Materials and Methods. (*Mech. World*, 1958, **138**, Feb., 65–66). A review of current practice is given with notes on various topics.

Graphite-Electrode Salt-Bath Furnaces. (*Engineering*, 1958, **185**, Feb. 7, 167). An account of the Efco-Upton unit is given. The bricks used last 3 years at 1000° C and 1–1½ for high speed steel hardening. For brazing 5–10 years is not uncommon.

Some Spring Heat Treating Practices Defined. J. Maker. (*Met. Treating*, 1958, **9**, Jan.–Feb., 2–3, 36, 42, 43). A general survey of furnaces and methods.

Method of Calculating the Heating Up of Furnaces with Multi-Layer Linings. E. M. Gol'dfarb. (*Stal'*, 1957, (12), 1131–1139). A method is described for the approximate calculation of the optimum conditions of heating up single and multilayer lined furnaces. This method takes into account the times of inertia, accumulation and equalisation.—R. S.

Modern Trends in Electric Furnace Practice. D. J. Williams. (*Austral. Eng.*, 1957, **50**, Dec. 7, 60–67). An illustrated review of all types of heat-treatment furnaces, controlled atmosphere systems and salt baths with an outline of their uses is given.

Heating at High Speed. N. H. Davies and R. J. Reed. (*Met. Prog.*, 1958, **73**, Feb., 79–84, 198). Factors influencing the rate of heating of metal parts in furnaces are considered and in particular the relative importance of convection and radiation. The results of previous work on heat transfer coefficients is summarized in graphical form. (21 references).—B. G. B.

Automation in Heating and Quenching. N. K. Koebel. (*Met. Prog.*, 1958, **73**, Feb., 72–78). Automatic equipment, available in the U.S.A., for heat treatment is described. The plants considered are for very small, medium and large and bulky parts.—B. G. B.

The Sulphiding of Mild Steel Surfaces. M. R. Piggott and H. Wilman. (*Acta Cryst.*, 1958, **11**, Feb., 93–97). Mild steel was reacted with sulphur and with H_2S and electron-diffraction studies were made. FeS, FeS_2 (marcasite and pyrites) and a new cubic form of Fe_2S_3 were observed.

Surface Treatment with Sulphur of Bronzes, Irons and Steels. D. Iturrioz. (*Met. Elect.*, 1957, **21**, Jan., 75–79; Feb., 45–49; Mar., 58–64.). [In Spanish]. In the first part of this article the effects of surface impregnation with sulphur are described and discussed. In the second part, data are given to indicate the improved frictional and wear-resistant properties and in the third part the author reviews the field of application, and describes industrial plant abroad, and in Spain, for the sulphur treatment of parts.—P. S.

On the Depth of the Enriched Sulphur Layer in the Sulphiding of Steels and Cast Iron. G. V. Karpenko, A. N. Tynnyi, and Yu. I. Babei. (*Vestnik Mashinostroenniya*, 1957, (2), 61–62). [In Russian]. The measurements were made in accordance with a procedure known as MAZ. The change of activity with the depth of the layer of the specimens has been plotted on graphs with the number of radiation impulses marked along the Y-axis, and the depth of the layer along the X-axis. Steel 45 and a sulphur cast iron were investigated and their curves are similar and assume an asymptotic shape. They are also similar for various other steels. Briefly the position is that the depth of penetration of the radioactive S in steel extends to 0·015–0·016 mm and in cast-iron to 0·034 mm, including the surface sulphur film. Such a metal surface has obviously antifriction properties, but owing to its thinness does not allow subsequent mechanical treatment.—L. H.

Hardenability Bands for Steels 4027-H to 4068-H. American Iron and Steel Institute. (*Met. Prog.*, 1957, **72**, Nov., 96-B).

Precipitation Hardening Stainless Steels. Heat Treatment and New Materials in the U.S. Aircraft Industry. A. C. Gilbraith. (*Met. Treatment*, 1957, **24**, Oct., 395–399). Armco 17-7 PH and 17-4 PH and Allegheny–Ludlum's AM-350 steels are described. Compositions and mechanical properties are given and their heat treatments are considered.

Controlled Flame-hardening: Use of Oxygen and Town Gas. (*Iron Steel*, 1957, **30**, Sept., 451–452). The introduction of the oxy-town gas flame, coupled with the Milliscope automatic temperature control and specially designed flowmeters for gas and O_2, has permitted consistent and controlled flame-hardening. A description is given of the system, developed by Peddinghaus, and of the four principal methods of flame-hardening: the progressive method, the spinning method, the combined method, and the spot method.—G. F.

Microscopical Research on the Change of Surface Structure of Metals during Gas Reactions. I. Gas Carburization of Steel. M. Kawakami and S. Uchida. (*Nippon Kinzoku Gakkai-Si*, 1955, **19**, Feb., 144–148). [In Japanese]. During gas carburization, grain boundaries on the polished surface of steel were seen to appear in 30 sec at temperatures as low as 650° C, and new grains began to grow. The carbon content of the surface reached the near-eutectoid composition quickly, and increased gradually up to the saturation concentration of austenite.—K. E. J.

Heat Treatment of Transmission Gears. (*Machinery*, 1957, **91**, Oct. 18, 920–922). David Brown Ind. Ltd. Automobile Gearbox Division practice is described. Gas carburizing, salt bath carburizing, and induction hardening are used.

Cementation of Iron by Carbon Monoxide. E. Mazanek. (*Arch. Hutn.*, 1956, **1**, (4), 341–367). Experiments on ore and on sponge iron are reported and compared with studies on electrolytic iron. Specimens were carburized in pure CO at 800, 900, and 1000° C for 2, 4, and 6 h in 2 mm sheet form. Carbon absorption is rapid over 800° and diffusion is more rapid than adsorption as shown by absence of soot. The rate was confirmed a proportional to $(\text{time})^{\frac{1}{2}}$. Sponge iron carburizes more rapidly than electrolytic iron and ore does not carburize appreciably until after ~ 70% reduction.

Light Petroleum Gas for Gas Carburizing. D. A. Colwell and J. S. Anderson. (*J. Austral. I.M.*, 1957, **2**, Aug., 45–47). A letter. Use in endothermic atmosphere generators is described, and carburizing and carbonitriding are illustrated.

Studies on Gas Carburization. I. Effect of Promoters on the Conversion Power of Charcoal for Town's Gas. M. Kawakami and N. Komuro. (*Nippon Kinzoku*, 1954, **18**, Mar., 158–163). [In Japanese]. The oxidizing constituents of Japanese town's gas hinder the carburizing power of the others, but this can be rectified by reduction of the gas with charcoal. The reducing power is promoted by carbonates of metals of Groups I or II, e.g. $BaCO_3$.—K. E. J.

On Cementation of Medium Alloy Carbon Steels. E. M. Morozova and A. P. Skysovatova. (*Stanki Inst.*, 1956, (3), 26–29). [In Russian]. Four marks of steel have been subjected to investigation with the result that an increase in the depth of the cementation layer from 0·5/0·7 mm to 1·3/1·5 mm increases the static strength of the specimens. The hardness of the layer decreases with its elimination from the surface, but with an increase in depth, the hardness of the layers nearest the surface is retained to a greater extent.—L. H.

Cementation of Special Steels With New Mixtures Based on Limestone and Dolomite. T. Farcas, T. Golgotiu, G. Ailincai, C. Ciochina, and E. Andrei. (*Bul. Inst. Politchn. Jasi*, 1956, **2**, (3/4), 335–349). Mixtures of $CaCO_3$ or dolomite with NaCl and charcoal were used on 8 alloy steels. Thickness of carburized layer and hardness were measured as a function of time and structures are shown.

The Influence of Surface Carburisation on the Course of Deformation of Steel. M. Žumer and V. Prosenc. (*Rudarsko-Metalurški Zbornik*, 1956, (4), 327–335). [In Serbo-Croat]. Ductility and the structures of surface-carburized O.H. test pieces of 0·06% C steel were studied. It is shown that even very thin surface layers having hypereutectoid structures lead to practically full brittleness, i.e. ductility is only about 1%.—P. F.

A Simplified System for Carbon Restoration. J. Arnold. (*Wire Wire Prod.*, 1957, **32**, Oct., 1201–1203, 1250–1253). Two systems are described, one consisting of N_2 generator, refrigerant gas dryer, desiccant gas dryer, mixing station for wet and dry N_2 and natural gas, and control instruments; the other including an additional endothermic generator with controls. The first system is surveyed and illustrated further, and sequence of operations, gas compositions, and reactions involved are set out. Microstructures show the course of C restoration.

A Study of Some Factors Affecting the Quality and Depth of Surface Hardening by High-Frequency Induction of Carbon Steels. M. P. Andrés Sanz. (*Inst. Hierro Acero*, 1957, **10**, July-Sept., 320–354). [In Spanish]. A detailed metallographic study of a range of plain carbon, hypoeutectoid steels after surface hardening is reported. The stages in progressive austenitization have been observed, this is affected by the initial microstructure which also influences the depth of penetration. Two steels (0·43% C, 0·26% Si, 0·61% Mn, and 0·53% C, 0·23% Si, 0·65% Mn) provide optimum characteristics for this method of treatment. When the surface layer has a hardness greater than 50 Rc it contains at least 50% martensite and is then suitable for such applications as wear-resistant parts. Data concerning the depth of penetration as a function of heating time and power input is also given.—P. S.

Industrial Utilization of High-Frequency Heating. (*Tecn. Indust.*, 1957, **36**, July, 817–822). [In Spanish]. The principles and advantages of dielectric and high-frequency heating are described. Typical applications are discussed and illustrated.—P. S.

Continuous Electric Direct Resistance Method for Heat Treating Steel Wire. O. C. Trautman. (*Wire Wire Prod.*, 1957, **32**, Oct., 1213–1218). The metallography of tempering is outlined and a process of electric heating and quenching and the properties of the wire obtained are described. Comparison with a gas-fired furnace and salt-bath quench is made.

Progressive Hardening of Mill Length Shafting with High Frequency Heat. (*Ind. Heat.*, 1957, **24**, Sept., 1780, 1782). Rods up to 4 in. dia. and 30 ft and over long are hardened without distortion on a mill with skewed roll arrangement with independent adjustment of feed and rotation speed.

Surface Hardening by High Frequency Induction Heating. Physical Principles and Metallurgical Considerations. M. P. de Andres. (*Inst. Hierro Acero*, 1957, **10**, Apr.–June, 200–210). [In Spanish]. A review is given of the process of induction heating and the following topics are considered: principles, choice, and effect of frequency, thermal effects of high frequency heating and temperature gradients within the metal, metallurgical effects and advantages of the process. (11 references).

Nitriding of Structural Steels. E. M. Morozova and A. P. Skuzovatova. (*Stanki i Instrument*, 1956, (9), 25–27). [In Russian]. The nitriding of 8 marks of steel showing substantial increases in surface hardness after nitriding is described. This process is recommended in cases where, together with durability, high surface hardness is required for minimum deformation after themal treatment.

Nitriding Moulds and Mould Parts Used in Pressure Die Casting. J. Červášek. (*Slévárenství*, 1957, **5**, (7), 198–201). [In Czech]. The network of cracks developing on mould surfaces in use is shown to be a fatigue phenomenon, and can be counteracted by methods which increase the fatigue limit of the metal or reduce the stress systems leading to their formation. Nitriding is particularly effective, as is shown by results obtained by the author with Cr–Ni–W–V, Cr–W–V, and Cr–Mo steels.—P. F.

Elimination of Decarburizing of Alloy Steel during Annealing in Protective Atmospheres. K. V. Dneprenko and M. M. Ioffe. (*Stal'*, 1957, (10), 934–935). In the annealing of 25KhGSA, 30KhGSA, and 25KhGFA sheets, decarburization was eliminated by enriching the protective gas with benzene vapour, by passing it through red-hot charcoal, and by removal of H_2S and CO_2 by scrubbing.

Annealing of Iron Strip and Wire during Cold Working. D. Grobovšek. (*Nova Proizv.*,

1954, **5**, (3–4), 254–259). The process at Jessenice is described.

Annealing in Protective Atmospheres of Vertically Stacked Sheets in Bell-type Furnaces. H. Preller. (*V.d.I.Z.*, 1957, **99**, Sept. 21, 1331–1332). The advantages of annealing and normalizing sheet steel stacked vertically in batch furnaces designed by E. Labovic (*Stahl u. Eisen*, 1956, **76**, 1741) are outlined, notably freedom from sticking, smaller temperature differences, better surface, shorter heating cycles and good mechanical properties. Drawbacks are smaller and charges and labour costs are higher, and heat losses somewhat higher than in conventional furnaces stacked horizontally.—J. G. W.

Comparison of Electric Resistance Patenting with Lead Patenting After Heating in a Gas-Fired Continuous Furnace. Parts I and II. E. Jaenichen, K. Schlegel, F. Greis, H. Krautmacher, and W. Püngel. (*Stahl u. Eisen*, 1957, **77**, Dec. 12, 1802–1810; 1810–1817). The authors describe a pilot plant built in their own works for electric resistance patenting. The wire passes through a lead bath which also acts as electrical contact. The wire is heated by the lead bath and by the electric current and reaches its maximum temperature immediately before quenching. The temperature of the lead bath was usually 515° C, but temperatures of 470–560° C were also used. Results of numerous trials are reported in detail. The quality of electrically patented wires is the same as that of conventionally patented wires up to 1% carbon with the exception of fatigue strength which is markedly higher for electrically heated wire.—T. G.

Increasing the Productivity of Vacuum Furnaces for Annealing Transformer Steel. B. M. Ioffe and S. M. Popov. (*Stal'*, 1957, (10), 948).

Comparison of Gas and Electric Strand Annealing Furnaces. H. Notarius. (*Wire Wire Prod.*, 1957, **32**, Oct., 1184–1187, 1277–1281). Complete analyses of two furnaces are given of the same size and operating under similar conditions, efficiencies, heat losses and costs are compared. The electric furnace is recommended.

Continuous Annealing at Velindre. (*Iron Steel*, 1957, **30**, Sept., 440). Brief details are given of the new strip cleaning and annealing plant at the Velindre works of Steel Co. of Wales Ltd. The plant is 210 ft long and 53 ft high, and handles 32 in. strip at a rate of 600 ft/min.—G. F.

Bogie Hearth Annealing Furnace For Whiteheart Malleable Castings. (*Ind. Gas*, 1957, **20**, Aug., 26–28). A description of a gas-fired furnace taking 112 pots of internal dimensions 1 ft 7 in. × 1 ft 4 in. high is given.

Lines Anneal Fast Without Soaking. (*Steel*, 1957, **141**, Oct. 14, 124–129). Four new continuous annealing furnaces for tin plate, at Bethlehem Steel Co. are described. Each has a capacity of 15 t/h. and a line speed of 500 ft/min. Heating time is only 3·6 sec, which allows a short line length across the building.

Homogenization of Structural Alloy Steels. W. Luty and A. Piotrowski. (*Arch. Hutn.*, 1956, **1**, (3), 217–249). A Cr–Ni–Mo steel was examined in "inter-operation" homogenization where diffusion annealing is carried out after plastic deformation by forging or rolling. Segregation was studied by electrochemical examination, a decrease of ~ 30% being noted after treatment at 1200–1250° C, especially in the first stage of 6–8 h, longer heating is therefore not recommended. Forgings were tested before and after homogenizing and improvements were noted in reduction of area, toughness, and elongation, the time taken being the same as in the electrochemical study. Structures were also examined.

Reconditioning of Plates and Sections by Means of Oxyacetylene Flames. G. W. von Cernik. (*Tecn. Indust.*, 1957, **36**, Aug., 961–967). [In Spanish]. The principles of the rectification of structures by means of controlled localized heating are discussed. Rules of procedure are established and many illustrations are provided to indicate the correct place and shape of a hot zone in order to produce the required effect in a particular section.—P. S.

Stress Relieving Welded Structures. (*Acciaio Inossid.*, 1957, **24**, July-Aug., 98–100). [In Italian]. Technical data are given on methods of stress relieving austenitic stainless steel welded structures. This can be carried out at low temperature, 450/500° C, or at high temperatures of 850 to 950° C—the best method depending on such factors as the type of stainless steel, the corrosive agents and working conditions, and finally the design of the structure.—M. D. J. B.

Ductile Iron: How Heat Treatment Upgrades It. R. S. Zeno and C. D. Walker. (*Steel*, 1957, **141**, Sept. 16, 132–134). Tests on a ductile iron in the as-cast, annealed, normalized and tempered, and oil-quenched and tempered states led to the conclusion that heat treatment can bring properties of an unsatisfactory ductile iron into specification.—D. L. C. P.

Austempering Is Mechanised. R. S. McFall and C. A. McFadden. (*Steel*, 1957, **141**, Sept. 23, 125–126). An automatic machine is described which heats, quenches, washes, and dries typewriter parts automatically. The type-bars are heated rapidly in a circular austempering furnace, dropped into a salt quench bath, sprayed, and warm-air dried. There are considerable savings over the previous method using 2 salt bath furnaces.

Pusher-Type Normalizing Furnace. (*Overseas Eng.*, 1957, **31**, Nov., 131). The electrically heated furnace of Albion Motors Ltd., Scotstown, Glasgow is described. The heating chamber is 10 ft 6 in. long and the cooling section 18 ft 3 in. The output is 600 lb/h heated to 900° C.

Lubricate Close Fits by Salt Bath Sulphurising. G. B. Troup. (*Iron Age*, 1958, **181**, Jan. 9, 72–74). Applications of the Lubri-Case process are described and explained. The process involves treatment of ferrous metals in a salt bath containing sulphur in an incompletely oxidised form. The resulting iron sulphide case provides excellent bearing surfaces. Higher speeds and loads, closer fits, and cheaper materials are made possible.

Hardenability Bands for Steels 4720-H to T50B60H. (*Met. Prog.*, 1958, **73**, Jan., 96B). Compositions and curves are given.

Controlling Carburized Case Depth. R. L. Suffredini. (*Mat. Design Eng.*, 1958, **47**, Jan., 118–119). A step-by-step procedure based on Rockwell hardness testing is described. A correlation for the steel and its heat-treatment schedule is required and shape and core hardness also may require corrections.

Surface Hardening by High Frequency Induction and Its Application in European Practice. M. Labrousse. (*Mét. Constr. Mécan.*, 1956, **88**, Sept., 725–731). A review of the use of this form of hardening and of equipment available is presented.—B. G. B.

Problems of Control During Surface Hardening by Induction. C. Di Pieri. (*Mét. Constr. Mécan.*, 1956, **88**, Nov., 931–937). The methods available for regulating the power supplied during induction heating are discussed.—B. G. B.

Heat Treatment by Induction as a Means of Increasing Wear Resistance in Heat Engines and Machines. G. W. Seulen. (*Mét. Constr. Mécan.*, 1956, **88**, Oct., 823–833). A general review of induction hardening is presented.

Carburisation and Decarburisation in Induction Furnaces Operated at Industrial Frequency. E. Calamari. (*Fond. Ital.*, 1957, **6**, Oct., 403–406). [In Italian]. The author reviews the advantages of a low-frequency induction furnace for use in a ferrous foundry and especially for making special cast irons and alloy steels. Laboratory and works carburation and decarburation tests are described and a number of industrial installations in Italy and abroad are referred to.

Carbo-nitriding. (*Tecn. Indust.*, 1957, **36**, Sept., 1131–1134). [In Spanish]. The principles and advantages of surface hardening by this method are described. Industrial plant for carbo-nitriding is illustrated.—P. S.

Continuous Annealing on a Grand Scale. C. E. Peck. (*Steel*, 1958, **142**, Jan. 20, 74–76). A continuous annealing line for tin plate strip at Wierton Steel Co. is described. The capacity is 60 t/h of strip 0·01 in. thick and 30 in. wide; strip speed is 2000 ft./min. The four sections are: 1, gas fired, radiant tube heating section: 2, electrically heated soaking section: 3, a slow cooling section with air tubes: 4, a fast cooling section with water tubes.—D. L. C. P.

Single Stack Annealing Gets the Nod. H. E. Miller. (*Steel*, 1957, **141**, Nov. 11, 118–126). The relative merits of multiple and single stack annealing furnaces are considered from experience at Republic Steel Corp. Operation, maintenance and quality factors favour the single stack.—D. L. C. P.

Increasing the Performance of Annealing Furnaces. J. Kolofík. (*Hutník*, 1957, **7**, (12), 402–404). [In Czech]. In the production of steel sheet the capacity of a continuous annealing furnace was found to be too small, necessitating operation on Sundays. It is shown how, by redesigning the furnace, its capacity was increased to meet works requirements. The criteria on which the reconstruction was carried out are discussed.

Detroit Steel's New Furnace Installation for Bright Annealing of Cold Rolled Strip. (*Ind. Heat*, 1957, **24**, Nov., 2313–2314, 2316). A bank of bell-type, radiant-tube, natural gas-fired annealing furnaces of 60-t capacity at the Portsmouth, Ohio, plant of Detroit Steel Co. is described.—A. D. H.

Modified Martemp Cuts Warping. E. C. Wallace and H. E. Crouse. (*Steel*, 1957, **141**, Dec. 2, 97–98). The advantages of a special system for martempering intricate and expensive parts are described. The method involves heating in a controlled atmosphere furnace and martempering at 260–275°F; cooling is followed by tempering and freezing treatments. Experience with precision pump blocks is described; difficulties with the following were minimized: warping, stabilization of structure, cracking, dimensional stability, plant losses.—D. L. C. P.

Prepared Annealing Atmospheres. G. J. Campbell. (*Steel*, 1957, **141**, Nov. 18, 160–175). Practical advice on preparing atmospheres for use in annealing of low carbon steel strip is given. Subjects include purification for sulphur, avoidance of carbon edge caused by CH_4, causes of surface etching and discolouration.—D. L. C. P.

How to Get More From a Spheroidizing Furnace. W. B. Leyda and W. J. Assel. (*Steel*, 1957, **141**, Dec. 9, 208–210). The operation of a controlled atmosphere, roller hearth furnace for spheroidizing seamless alloy steel tubing is described. The furnace chamber is 70 ft. long with loading dimensions 7 ft. wide and 16 ins. high; there are also sealed charge and discharge vestibules. The product has high uniformity.—D. L. C. P.

Which Should You Ask For: Normalizing, Annealing, or Stress Relieving? A. S. Eves. (*Met. Treating*, 1958, **9**, Jan.–Feb. 16–17, 34). A review of the processes, their purposes and results.

Quenching Media and Their Cooling Properties. L. Procházka. (*Hutník*, 1957, **7**, (12), 413–417). [In Czech]. The quenching abilities of various gaseous and liquid media are represented in terms of the rate of cooling of a pre-heated silver sphere of 0·8 in. diameter submerged in them. The data compiled from the literature are useful in work involving quenching and tempering.

New Way to Measure Quenching Speed. E. A. Bender and H. J. Gilliland. (*Steel*, 1957, **141**, Dec. 30, 56–59). A magnetic quenching test devised by General Motors Corp. is described. A nickel ball, heated to 1600° F, is quenched in the medium under test, and the time taken for it to become magnetic (at 670° F) is measured. Some results were correlated with transverse hardness tests and excellent agreement obtained. The test can be used to compare oils or salts, and to evaluate other factors which change quenching rate.—D. L. C. P.

Advantages of Fast Quenching, and Common Misconceptions. F. M. Aldridge. (*Ind. Heat*, 1957, **24**, Nov., 2301–2302, 2304). The action of a proprietary additive in improving the properties and life of quenching oils is described.—A. D. H.

How to Measure the Effects of Slack-Quenching. (*Iron Age*, 1958, **181**, Jan. 23, 80–82). A test developed at the National

Bureau of Standards for measuring the effect of slack-quenching on the impact resistance of steel is described. A Jominy bar is end-quenched and the location of the desired hardness or microstructure determined. This has been correlated with the distance of this structure from the immersed end of an impact specimen, and this relation is given in a graph. Such a specimen can be made, notched at the appropriate point, and tested.—D. L. C. P.

Electronic Signaller Reduces Quench-cracking of Steel. P. M. Unterweiser. (*Iron Age*, 1957, **180**, Nov. 28, 79–81). An apparatus has been developed which indicates the hardness of steel being quenched. It is hoped that this control will allow quenching to be terminated at the optimum time, thus reducing quench cracking. The method involves measuring magnetic permeability, using alternating current in a coil around the work.—D. L. C. P.

FORGING, STAMPING, DRAWING AND PRESSING

Indentation and Forging and the Action of Nasmyth's Anvil. W. Johnson. (*Engineer*, 1958, **205**, Mar. 7, 348–350). An examination of the pressure required to indent a block of metal by three or more dies of equal width placed symmetrically is presented. Other solutions for various other conditions of indenting and forging are given with approximate methods of analysis. Forging in V-anvils is considered.

Switch to Forgings Beefs Up Products. H. E. Jackson. (*Western Metalw.*, 1957, **15**, Dec., 52–52). The article describes how a firm increased its range of products and raised its output by changing from castings to forgings. Main products were caterpillar tracks and aluminium gear parts for Jeeps. The forging equipment is illustrated.—E. S.

How To Avoid Cracking Die Steels. (*Steel*, 1957, **141**; Sept. 30, 79–82; Oct. 7, 200–202). Factors conducive to reliable tool and die production are considered; they are covered by the headings Design, Machining, Heat treatment, Material selection. Illustrated examples of cracked parts are given and explained.—D. L. C. P.

Production of Metal Products for Industrial Use. N. I. Kadykov. (*Stal'*, 1957, (11), 1014–1016). A review.

Look What's Happening to Honeycombs. (*Steel*, 1957, **141**, Oct. 14, 116–119). Types and properties of plymetal honeycomb are described, and methods of manufacture are considered in some detail. Particular attention is paid to stainless materials.—D. L. C. P.

New Method Cuts Cost of Short Run Stamping. (*Iron Age*, 1957, **180**, Oct. 3, 93–95). The method described gives low-cost, close-tolerance, short-run stampings. Cheap tooling more than compensates for the several steps involved. Specially designed cushion blanking dies can be used at 100–250 times per min.; piercing is done on special presses, one for each size hole, with the work held in a jig.

A Method for Increasing the Strength of 1Kh18N9T Steel Sheet Used for Hot Stamping. V. K. Barzii and S. S. Kolot. (*Stal'*, 1957, (10), 950).

Stamping Plates to Close Tolerances. (*Steel*, 1957, **141**, Aug. 26, 72–73). The operation and advantages of a stamping process, in which 2 parts of an exhaust elbow tube are formed with sufficient accuracy for welding, are described. Material is ¼ in. mild steel.

Influence of Friction on the Resistance to Deformation of Metals in Stamping. S. Valente. (*Ing. Mecc.*, 1957, **6**, Sept., 41–45). [In Italian]. The Siebel theory of the influence of friction on the resistance to deformation of metals is verified experimentally, and it is shown that the metal flows in the direction of least resistance. Examples of immediate practical value are described. Technical data are given in tables and graphs.—M. D. J. B.

"Slugging" versus Bar Turning. (*Metalw. Prod.*, 1957, **101**, Nov. 1, 1960–1963). A comparison of methods at 5 factories shows that the use of cut-off blanks is often economical of machine time, labour, and space. Costs are indicated.

Deep Draw Disc for One-Piece Gas Container. (*Iron Age*, 1957, **180**, Oct. 10, 122–123). Types of portable pressurized gas cylinders, and their contents are described. The production of one-piece, disposable, CO_2 cylinders for inflating life jackets is described; 0·065 in. cold rolled steel or brass discs are deep drawn in 5 steps, and the filling end is shaped before loading with liquid CO_2 at 845 psi.—D. L. C. P.

Deep Hot Drawing of Thin Sheets of Certain Metals and Alloys at Different Speeds. N. A. Klyucharev. (*Vestnik Mashin.*, 1957, (8), 40–45). [In Russian]. The experiments were carried out on sheets of thickness between 0·5 and 2mm. The increase in the speed changes the conditions and the characteristics of the drawing. The experiments prove the possibility of increasing the speed to 10 cm/sec which is very considerably greater than the speeds used in previous experiments.—L. H.

Method of Representing the Drawing Process on Non Slip Cumulative Machines by Graphical Means. Kowalski. (*Wire*, 1957, Aug., 20–22). In this article a graphical method is outlined for analysing drafting on multi-hole, non slip, cumulative machines. The method is based on plotting drawing speed against wire diameter on log–log paper.—J. G. W.

Chemical Capping Cuts Drawing Rejects. J. S. McNairn. (*Steel*, 1957, **141**, Aug. 26, 76–78). Experience with chemically capped steel at Ford Motor Co. is described. With this type of steel, top cut segregation is minimized and the whole ingot is suitable for deep drawing. Limitations to the process are noted, but 2×10^4 t of this steel have been used with advantage.—D. L. C. P.

The Cold Pilser Process and its Value in Comparison with Cold Drawing. F. W. Neumann. (*Z. Metallk.*, 1957, **48**, Oct., 564–568). The Rockrite process of cold tube reduction and die forming methods are reviewed. Flow in this process is compared with cold drawing, and ball races and special ferrous and non-ferrous tube production are discussed.

Brief History and Modern Trends in the Manufacture of Pipes and Tubes. D. N. Chatterjee. (*Tisco*, 1957, **4**, 212–226). The author introduces briefly the history of tube making and then describes the various methods now used, viz. the Fretz–Moon process, the Electric-Resistance-weld process, and the seamless process. The latest developments in tube making, such as stretch reduction and the Ugine-Sejournet process, are also dealt with.

Seamless Steel Tubes. (*Lastechn.*, 1957, **23**, (10Lp), Oct., 233–234). [In Dutch]. This is a general description of the Mannesmann Pilger process for seamless steel tube and pipe manufacture followed by reference to the numerous industrial uses to which the tubes may be put and also to the often exacting requirements expected of them.—F. R. H.

Drawing and Threading of Cold Rolled Steel Bars. W. Dahl and W. Lueg. (**Stahl u. Eisen*, 1957, **77**, Dec. 12, 1795–1802). Mathematical. Based on the theory of R. Hill ("The Mathematical Theory of Plasticity," Oxford: 1950), the authors deduced an equation for the ratio of the threading to the drawing force. This equation is in good agreement with measured results. The values, in particular the effect of the friction coefficient, are presented in many graphs and discussed in detail.—T. G.

Appropriate Rods for Appropriate Wire. J. P. De Witte. (*Wire Wire Prod.*, 1957, **32**, Oct., 1207, 1210–1212, 1268–1272). A discussion of rod and wire quality with control operations, grades of steel used, and improved production methods such as the use of O_2 and their advantages and the properties of the finished wires, and a discussion of the effects of dislocations is added. (24 references).

Formulae for the Calculation of Forces in Steel Wire Drawing. E. Ravelli. (*Ing. Mecc.*, 1957, **6**, Sept., 49–54). [In Italian]. The author compares a number of formulae put forward by various authorities for the calculation of forces required in steel wire drawing. The practical value of the formulae is discussed. (44 references).—M. D. J. B.

Steel Wire for Needle Manufacture. J. Domorazek. (*Wire Prod.*, 1957, **6**, July-Aug., 5, 7, 9, 11; from *Strojírenství*, 1956, (11), 746–750). Composition, metallographic structure, and physical properties are discussed. The effects of production methods on plasticity, toughness, surface quality, and defects are outlined and improved inspection methods are advocated.

Recent Developments in Steel Wire Drawing Machinery. J. E. Spearman and M. A. Nye. (*Wire Wire Prod.*, 1957, **32**, Oct., 1228–1231, 1266–1268). A review of machines made by the Vaughn Machinery Co., Ohio.

Cold-Forming Wire or Strip Material. (*Auto. Eng.*, 1957, **47**, Sept., 356–360). The Heenan 81½ hydraulic multiform machine and its operation and products are described.

Lubricants and Their Carrier Surfaces in the Drawing of Steel Wire.—II. W. Dahl and W. Lueg. (*Stahl u. Eisen*, 1957, **77**, Oct. 3, 1369–1374). The authors studied the suitability of phosphate films as lubricant carriers using a variety of mineral and vegetable oils with high-duty additives and MoS_2 and silicone oils, etc. They found that none of these materials had the good properties of drawing soap.—T. G.

Cold Extrusion of Steel. B. Kaul. (*Machinery*, 1957, **91**, Oct. 25, 963–968). The cold extrusion of hollow cylinders with integral bottom portions is described. The production of pressure tubes is taken as an example and intermediate annealing and forward and backward extrusions are considered.

Work Handling on a Twin-Duty Extrusion Line. R. H. Duncan and B. C. Brosheer. (*Metalw. Prod.*, 1957, **101**, Oct. 18, 1872–1876). Production of ball joint suspensions by forward extrusion of steel is described with special reference to lay-out and automatic and fork-truck operations.

Rapid Reheating Methods and the Use of Salt Baths in Steel Forging. S. Hájek. (*Hutník*, 1957, **7**, (7), 234–236). [In Czech]. It is shown that the use of salt baths is a suitable method for reheating in die forging, particularly in the case of high quality steels, as a scale-free surface is obtained.—F. F.

The Working of Special Steels. G. Grenier. (*Echo Mines*, 1957, Dec., 716–718). A review of compositions, soaking pit practice, forging and rolling at a large number of works in France and elsewhere is presented.

How to Upgrade Cold-Finished Steel. L. J. Ebert. (*Steel*, 1957, **141**, Dec. 23, 66–69). The effects of cold-work on steel are considered. There is a range of cold working which has little effect on strength; larger or smaller amounts are more effective. Large reductions give valuable high strength levels, and other benefits.—D. L. C. P.

4,500 Ton Hot Plate Press Installation. (*Engineer*, 1958, **205**, Jan. 31, 171–173). An illustrated account of the press installed by Whessoe, Ltd., at Darlington is given.

Punch Life Increased 200 Times. (*Metalw. Prod.*, 1958, **102**, Feb. 21, 335). Punches for automobile rear-axle housing flanges were metallized with Mo and then had a life of 50,000 pieces against the 200–250 of conventionally hardened, Cr-plated or carbide punches.

Dieing Machine Does Many Jobs for Contract Stamper. W. H. Dutcher, jun. (*Iron Age*, 1958, **181**, Jan. 9, 68–69). The use of a new press in a contract stamping shop is described. It is designed to work at up to 120 stokes/min. on coiled stock—D. L. C. P.

Choice of Stock Cuts Scrap Losses. H. Chase. (*Iron Age*, 1957, **180**, Nov. 28, 90–91). The advantages of using coiled instead of sheet stock for making a stamped stator ring, are explained.—D. L. C. P.

Speed Effects in Deep Drawing. H. T. Coupland and D. V. Wilson. (*Sheet Metal Ind.*, 1958, **35**, Feb., 85–103, 108). The cupping test and the equipment used are described. A rimming steel with 0·075% C, 0·024% S, 0·013% P, 0·36% Mn, 0·07% Ni, 0·07% Cu and 0·01% Sn was used, rolled to 0·04 in and box-annealed. Drawing tests to determine the effects of speed and lubrication were carried out. Tests on brass were also made.

Use of Coated Steels in Drawing. N. E. Hays. (*Ind. Fin.*, 1957, **9**, Sept., 811–812). The improvement in deep drawing properties

obtained with phosphated zinc-coated strip is pointed out.—A. D. H.

How to Remedy Defects in Drawn Shells. F. Strasser. (*Iron Age*, 1957, **180**, Nov. 21, 125–127). Remedies for the following defects which are liable to occur in the initial stages of shell drawing are considered: torn bottoms; wrinkles; uneven height; ruptured walls; bulging and buckling; burnished surfaces; scratched, scored or pitted areas; step rings.

Zigzag Bends for Longspan Steel Joists. (*Western Metalw.*, 1957, **15**, Dec., 56). This brief note illustrates a machine to bend bars to form the zigzag webs of long steel joists. The machine produces 50 web bars per h.

Lubrication in Wire Drawing. J. G. Wistreich. (*Wire Ind.*, 1957, **24**, Oct., 954–958; Nov., 1027–1029, 1046). The paper is devoted to physical aspects of wire-drawing lubrication, with a distinction drawn between drawing to size when the best possible lubrication is required and drawing for surface finish when lubrication is deliberately restricted to the minimum compatible with freedom for scuffing. A quasi-hydrodynamic regime is found to prevail when drawing to size and a method of "forced" lubrication is described, inducing fluid-film conditions. One form of the method is on the way to being applied in the industry following spectacular reductions of die wear achieved in mill trials. Included is a discussion of the properties of wire-drawing soaps and of the feeding of soap.

Determination of Die Wear in Wire-Drawing by Means of Radioactive Isotopes. E. Lindstrand. (*Jernkont. Ann.*, 1957, **141**, (12), 837–846). [In Swedish]. Irradiated WC dies were used with activities of 300mC ^{187}W and mild steel was drawn from 11 to 12·5 S.W.G. A thin shaving was taken from the wire and packed in glass tubes fitting into a scintillation detector. The wear rates measured ranged from $0{\cdot}5 \times 10^{-2}$ to 5×10^{-4} g/m of drawn wire and the method appears to be simple and well suited to die wear measurement when lubrication is good.

Manufacture of Upholstery Springs. E. Flowers. (*Wire Ind.*, 1957, **24**, Oct., 931–936). The metallurgical changes in mild steel and carbon steel wire used for upholstery springs as the result of heat treatment and drawing are explained, followed by a brief outline of the heat treatments used for the springs.—J. G. W.

Cutting Stock Preparation Costs. (*Steel*, 1957, **141**, Dec. 9, 192–193). The integrated facilities for prepering mill-finished wire for boltmaking at Cleveland Screw Cap Co. are described and illustrated. Processes involve cleaning, annealing and drawing.—D. L. C. P.

Experience with Cold Extrusion. (*Metalw. Prod.*, 1958 **102**, Jan. 31, 194–196). Illustrated notes with brief descriptions on various aspects of the process.

Cored 90 mm Gun Tubes Extruded in 5 Minutes. H. J. Decelle, A. A. Krystofik and J. Penrose. (*Metalw. Prod.*, 1958, **102**, Jan. 31, 190–193). An illustrated account with micrographs showing flow lines.

Impact Extrusion. (*Mach. Shop Mag.*, 1958, **19**, Mar., 139–142). The process has, so far, mainly been used for non-ferrous metals but the lower carbon steels are quite suitable. Phosphate treatment in conjunction with a lubricant is usual. Typical shapes are illustrated and presses are briefly described. Automobile parts are regarded as suitable for the process.

Impact Extrusion of Steel. H. W. Byles. (*Metalw. Prod.*, 1958, **102**, Jan. 31, 201–203). A review with special reference to future prospects. Typical products are shown.

ROLLING MILL PRACTICE

Metal Flow in Oblique Rolling. S. Mise, T. Okamoto and A. Funatch. (*Sumi. Met.*, 1957, **9**, July, 143–157). Solid billet piercing in Mannesman-type mills was examined by interrupting the process and studying displacement and deformation in sections cut transversely.

On Electrical Gear Used in Sheet Rolling Mills. A. Honců. (*Hutník*, 1957, **7**, (8), 269–272). [In Czech]. Basic principles of design, choice and servicing of driving gear and other accessories are discussed.—P. P.

Vacuum-Lift Transfer Unit Positions Heavy Plate. (*Iron Age*, 1958, **181**, Jan. 9, 70–71).

Towards Better Steel. W. Richards. (*Tin-Printer & Box Maker*, 1957, **33**, Oct., 4, 7). A note on tinplate mill developments and the effects of ingot non-homogeneity.

Metallurgical Characteristics of the Flanders Sheet Made by the C.S.N. P. Silva. (*Bol. A.B.M.*, 1957, **13**, Jul., 215–244). [In Portuguese]. This article is designed to explain the metallurgy and properties of the types of sheet that the Cia. Siderurgica Nacional produce, or will produce, to interested consumers. Production was about 77,000 t in 1956 and it will eventually be 150,000 t. Details of compositional requirements, deoxidation practice, mechanical working and heat-treatment sequences for suitable steels are given and followed by details of sizes, gauges and tolerances. Finally, the author discusses the immersion and electrolytic tinning methods employed and indicates the various qualities of sheet produced.—P. S.

The Development of Automation in Rolling Mills in the USSR. E. Červený. (*Hutn. Listy*, 1957, **12**, (11), 1053–1056). [In Czech]. The systematic development of automation and its application in the Soviet Steel Industry is traced. In the current 5-year plan, forty rolling mill alleys of various types will be automated. Although the social system in Czechoslovakia should be as conducive to rapid automation as in the USSR, progress in this field has not been equally satisfactory.

Utilisation of Soviet Experience with the Use of Negative Tolerances in Rolling in the Molotov Steelworks in Trinec. (*Hutník*, 1957, **7**, (10), 343–345). [In Czech].—P. P.

Characteristics of the Thin, Cold-Rolled Sheet Produced by the Cia. Siderurgica Nacional. S. E. Friedrich. (*Bol. A.B.M.*, 1957, **13**, Jul., 245–266). [In Portuguese.] Three types of steel are produced: (i) for deep-drawing (0·05–0·08% C, 0·25–0·50% Mn, 0·030% max. P and S); (ii) for vitreous enamelling (0·03–0·05% C, 0·10–0·18% Mn, 0·015% max. P and 0·025% max. S); and (iii) for other uses (0·09% max. C, 0·25–0·50% Mn, 0·040% max. P and 0·050% max. S); their production is described briefly. Each type is then discussed in detail, the requirements and characteristics being indicated. Control tests of the deep-drawing steels are examined and the metallographic control tests for formability to be adopted by the Company are explained. Finally, the different finishes, e.g., bright and blue annealing, temper-rolling, and stretching are described together with their drawbacks.

Mechanical Tubing. J. C. Merriam. (*Mat. Design Eng.*, 1957, **46**, Dec., 127–146; Manual No. 144). Available types and shapes of C and alloy steels, stainless steel and non-ferrous tubes are reviewed.

Special Machinery Slits Tough, Ultra-Thin Alloys. D. Stewart. (*Western Metalw.*, 1957, **15**, Dec., 46). A special technique for slitting and roller levelling extremely thin (0·004 in) stainless and silicon steels and titanium is described. High speed cutters are used.—R. S.

Controlling Non-Stop Steel Processes. (*Elect. Times*, 1958, **133**, Feb. 13, 245–248). Electronic apparatus on a strip mill is described.

The Application of Pneumatic Gauging Techniques to Strip Edge Grinding Machines. M. Graneek and C. A. Scoles. (*Sheet Metal Ind.*, 1958, **35**, Feb., 109–112).

Photoelectric Pyrometer for Measuring the Metal Temperature during the Hot Rolling Process. A. Machalski and K. Lubecki. (*Prace Inst. Ministerstwa Hutnictwa*, 1957, **9**, 161, 281–289). A discussion of requirements suggests the suitability of optical methods and disappearing filament, photoelectric and other types are considered. A photoelectric pyrometer is described working over the range 750–1300° C and a trial on the plant has shown its suitability.

Automatic Marking Gains Favour. (*Steel*, 1957, **141**, Nov. 25, 100). The use of an 18-digit slab-marker in a 90 in. slabbing mill being erected for Republic Steel Corp. is described. Remote controlled, the machine will mark slabs heavily with ingot number, heat number and cut description.—D. L. C. P.

MACHINERY FOR IRON AND STEEL PLANT

Steelworks Bulk-Materials Handling Innovations. (*Mech. Handling*, 1958, **45**, Mar., 152–156; *Overseas Eng.*, 1958, **31**, Mar., 294–295). Practice at the Margam and Port Talbot works is described and illustrated. Furnace demolition, stockpiling and reclaiming with rubber-tyred vehicles and the use of rubber tyred cranes are considered.

Vacuum Crane Speeds Mill Output. (*Steel*, 1957, **141**, Dec. 2, 102–105). The vacuum cranes described handle austenitic stainless steel sheet (non-magnetic). This method of handling avoids scratching the stock. Six suction cups are used.—D. L. C. P.

The Steelworks Power Station of Richemont. R. Placet. (*Tech. Mod.*, 1957, **49**, Dec., 660–669). A power station burning blast furnace gas as well as coal is described.

Gas Turbine for a Steel Works. (*Steam Eng.*, 1958, **27**, Mar., 202–205). A 2500 kW gas turbine alternator running on blast furnace gas for installation at a steel works is described.

Steelworks Trio of 90-Ton Shunters. (*Oil Engine and Gas Turb.*, 1957, **25**, mid Sept., 180–181). An account of 660-h.p. oil-engined shunting engines for the Steel Co. of Wales.

Non-Inflammable Liquids For Hydraulic Systems. (*Echo Mines*, 1958, Jan., 43–44). A section on uses in iron and steel works is added.

WELDING AND FLAME CUTTING

A Summary of the Work of the British Welding Research Association on Welding Low-Alloy Steels. P. H. R. Lane. (*Brit. Weld. J.*, 1958, **5**, Jan., 38–42). Work since 1938 on the development of a high-strength weldable steel, on the mechanism of cracking the heat-affected zone and an account of the weldability test are given.

Rapid Transformation in Resistance Welding of Carbon Steels. I. Hrivňak. (*Zváranie*, 1957, **6**, (10), 297–299). Electron microscopical studies of retransformed pearlite and the decomposition phases formed in rapid welding are described. In these transformed structures separation of pearlite at an angle of 60° occurs.

The Arc Welding of Carbon Steels in CO_2 Atmospheres. C. Penche Felgueroso. (*Cien. Tecn. Solda.*, 1957, **7**, July-Aug.). [In Spanish]. A review, with illustrations, of the papers dealing with this subject is given. (20 references).—P. S.

Metallurgy of Submerged-Arc Welding. M. Komers. (*Schweisstechn.*, 1957, **11**, Sept., 97–100). The composition, properties, and behaviour of different types of powders used in the submerged-arc welding process are discussed.—U. E.

Saving in Cost and Improvement in Efficiency in Track Construction using Oxy-Acetylene Welding. W. Kilbert. (*Schweissen u. Schneiden*, 1957, **9**, Sept., 424–428). The advantages of oxy-acetylene welding applied to track construction are discussed together with saving in costs and increase in efficiency.—U. E.

Friction Welding of Steel. B. Vrána. (*Zvár. Sborník*, 1957, **6**, (3), 327–347). [In Czech]. Applications, and technological and economic aspects of the method are considered in detail. Results of experiments designed to obtain optimum conditions in the weld-repairing of tools are given.—P. P.

Construction of a Basic Bessemer Pipe Line. O. L. Bihet and A. Gourlez de la Motte. (*Rev. Soudure*, 1957, **13**, (3), 180–188). [In French]. This paper gives the results of a detailed investigation carried out to determine the mechanical and welding properties of certain basic Bessemer steels specially produced for pipe-lines. Considerable data on chemical analyses, mechanical properties, and resilience values are given in table form. A number of charts and microphotographs are also given.

Autogenous Welding When Laying Pipe Lines. H. Jansen. (*Lastechn.*, 1957, **23**, (10Lp), Oct., 254–260). [In Dutch]. The article gives a general description of the usual methods adopted when jointing and laying pipe-line

installations. The suitability of the autogenous method of welding for pipe lines and its advantages are discussed in conjunction with numerous practical illustrations of a variety of pipe-lines which appear in the text.

Welding of Shapes and Reinforcing Members Used in Concrete. T. Nawrot and Z. Wieslawski. (*Zvár. Sborník*, 1957, **6**, (3), 314–326). [In Slovak]. Theoretical aspects of the strength and fatigue-strength of welded structures made from standard shapes are developed, and are shown to give good agreement with results obtained experimentally.—P. F.

Welding Thin Walled Tubes in Aircraft. N. Groenendijk. (*Lastechn.*, 1957, **23**, (10Lp), Oct., 261–264). [In Dutch]. The author lists the various types of materials and alloys used for tubular structures—fuselage and pipelines—of aircraft, indicating their composition and physical characteristics. He then goes on to show the advantages and disadvantages of the different methods adopted for welding them together to the required conformation.

Butt Welding of Ferritic Steel Boiler Tubes by the Arc and Flame Processes. J. Hennion. (*Soud. Techn. Connexes*, 1957, **11**, Sept.-Oct., 323–332). The author compares characteristics of the arc and flame welds on Cr–Mo steel tubes up to 90 mm dia. and 9 mm thick. The effects of preheating and heat treatments are discussed, also methods of heating and inspecting welds.—B. P.

On a Visit to the Brissonneau and Lotz Works. (*Soud. Techn. Connexes*, 1957, **11**, Sept.-Oct., 290–294). The report describes the welding processes and equipment used for the fabrication of rolling stock for railways, aircraft parts, and apparatus for sea and inland waterway transport.—B. P.

Weld-Repairs of Railway Carriages. S. Škerjanec. (*Varilna Tehn.*, 1957, **6**, (2), 33–36). [In Serbocroat]. Successful repair of the chassis of a four-axial freight car by insertion of a steel patch is described. Details of the weld-technology, including the mechanical working of the weld by hammering, are given.

Methods of Joining Pearlitic and Austenitic Parts of High-Pressure Steam Tubing. R. Doležal. (*Sborník Vědeckých Prací Vysoké Školy Báňské v Ostravě*, 1956, **2**, (4), 53–65). [In Czech]. Methods of joining in common practice in work with steam superheated above 550° C are reviewed. New methods developed by the author, which are free from some of the undesirable features of existing practice are described, and detailed calculations facilitating their application are given.—P. F.

The Application of Modern Welding Processes to Steel and Malleable Iron Castings. H. Zeuner and K. Zimmermann. (*Giesserei*, 1957, **44**, June 20, 382–388). The various welding methods available are described in some detail. The different types of electrode that can be used are then enumerated and discussed. The effect of alloying elements on the weldability of (*a*) white weldable malleable cast iron, (*b*) un-alloyed steel castings, (*c*) high strength and hot strength steel castings and (*d*) corrosion-resistant steel castings is discussed. Finally, practical examples of the application of welding methods to the production of finished castings are described and illustrated.—R. J. W.

The Application of Welding Methods to Cast Iron. C. Hase. (*Giesserei*, 1957, **44**, June 20, 370–373). The operating methods and the range of application of oxy-acetylene and electric arc welding processes are first described and compared. Calculations are made of the relative costs of hot and cold welding. Thermal cutting processes are then discussed. Finally the use of the welded joint as a design medium is considered.—R. J. W.

The Metallurgy of Welded Heat-Resistant 12% Cr + Mo–V–W Alloy Steels. E. Kaubausen and P. Kaesmacher. (*Schweissen u. Schneiden*, 1957, **9**, Sept., 414–419). The applicability of heat resistant 12% Cr steels at temperatures up to 580° C which involves welded structures is investigated. It is shown that great care must be taken when welding to avoid cracking. Several types of alloyed basic-lime electrodes are described, some of which contain cobalt and their behaviour is discussed.—U. E.

Welding, a Factor of Economy and Rapidity in the Repair of the Rolling Stock of the Italian State Railways. C. Bologni and M. Voltolini. (*Cien. Tecn. Solda.*, 1957, **7**, May-June). [In Spanish]. Various examples of welding repairs of railway equipment ranging from fireboxes to cylinder heads are illustrated and discussed in order to indicate the possibilities of improvement in efficiency and economy. The authors point out that careful choice of quality, labour, and technique is necessary in order to realize these advantages.—P. S.

On the Problem of Cutting Tools Made by Welding. J. Škriniar. (*Zvár. Sborník*, 1957, **6**, (3), 348–360). [In Slovak]. A number of electrodes were developed for experimental purposes, and tested by making weld-on cutting surfaces for tools used in chip-less machining. An electrode of ledeburitic 12% Cr steel of the following composition was found most suitable on assessing all test data: 1·94% C, 0·69% Mn, 1·14% Si, 10·4% Cr, 0·72% Mo.—P. F.

The Welding of Crude Steel Ingots. G. Wycisk. (*Neue Hütte*, 1957, **2**, July, 400–404). The results of tests on welded and subsequently worked steel ingots weighing 300 kg show that the welding of steel ingots in the manufacture of disc wheels is feasible. The transition from the weld to the steel was free from defects, the microstructure of the weld being finer than that of the steel. The decrease in hardness was very gradual, amounting to no more than 20 Kg per mm² (Brinell).

Technology of Arc Welding of Light-Gauge Sheet Steel in an Atmosphere of Carbon Dioxide. F. E. Tret'yakov, A. B. Karan, and S. N. Valeev. (*Svarochnoe Proizv.*, 1956, May, 20–22). Work on the manual and automatic welding of EI654, 12G2A, 25KhGSA and 30KhGSA steels 1–3 mm thick is reported. The CO_2 supply had an electric heater to prevent solidification and a drying vessel. Welding conditions are shown and analyses of parent and weld metals given. The cost is 1/8 to 1/10 that of A protection.

Welding Speeds Bridge Construction. W. P. Douglas. (*Iron Age*, 1957, **180**, Oct. 10, 124–125). Welding methods being used for components of the superstructure of a new San Francisco Bridge are described. The long heavy sections are fillet welded by submerged arc; suitable automatic, mechanized or manual methods are used.—D. L. C. F.

Butt Weld Tinplate Faster. (*Iron Age*, 1957, **180**, Oct. 10, 121). The equipment described shears and welds the ends of tinplate coils in such a manner that the joint area can be used. It will handle tinplate down to 0·006 in. thick and up to 38 in. wide. Average time for one operation is 40 sec.—D. L. C. F.

Metallography of Powder-Powered Fastenings in Mild Steel. C. J. Osborn and N. E. Ryan. (*J. Austral. I.M.*, 1957, **2**, Aug., 48–53). Driving of fasteners by power cartridges produces local welding and high temperatures at the interface are also indicated by martensite formation. Fasteners cold-headed from bright-drawn wire might be superior to those machined from solid bar. The Cd plate used on fasteners appears to act as a lubricant.

Means of Reducing Hydrogen Content of Welds in Mild Steel. M. Lefevre. (*Rev. Soudure*, 1957, **13**, (3), 189–194). [In French]. The author describes a number of factors which can influence hydrogen content in welds. These are: The humidity of the electrode covers, the humidity of the air at the moment of welding, weld temperature, welding speed and the speed with which hydrogen is diffused. The hydrogen content can be very appreciably lowered by heat treatment. It is claimed that basic electrodes will always give a lower hydrogen content in the weld.—M. D. J. B.

Desulphurization of the Weld Bath in Electric Arc and Electric Slag Welding. Yu. A. Sterenbogen, Yu. V. Latash, B. I. Medovar, and Yu. N. Zaitsev. (*Avtom. Svarka*, 1957, (4), 71–74). [In Russian]. The possibility of using metallurgical slags for desulphurization under welding conditions has been studied and checked with steels and cast iron. Better quality of weld metal is said to be obtained with such slags.—S. K.

Plant for Heavy Welded Steel Fabrications. (*Met. Treatment*, 1957, **24**, Nov., 469–470). A description of the Old Park Engineering Ltd. works at Dudley is given.

Electrode Quality Depends on Coating. H. F. Reid. (*Steel*, 1957, **141**, Sept. 30, 83–84). The function and importance of electrode coatings on weld quality are indicated.—D. L. C. F.

A Contribution to the Development of Oxy-acetylene Welding Rod for Weld Alloying from the Coating in Place of Alloyed Welding Rods. F. Erdmann-Jesnitzer and J. Wodars. (*Zváranie*, 1957, **6**, (10), 299–304). The process can be carried out with the torch as well as in arc welding and a deposit of the required composition can be obtained without much variation.

5 CH 5 Electrodes for Cast Iron Welding. P. S. Elistratov. (*Stanki i Instrument*, 1955, (7), 35). [In Russian]. These electrodes consist of steel bars with suitable covering. They can be made from low carbon steels with 0·15–0·20% C. The coating consists of two components, marble and haematite in equal quantities. A full description of manufacture is appended.—L. H.

Joining Mild Steel ? How to Select the Right Electrode. C. Cambell. (*Can. Metalw.*, 1957, **20**, Sept., 48, 50, 52, 54). Requirements are classified as "fast freeze," "fast follow," and "fast fill" and choice of electrode is discussed.

Austenitic Electrode with 20% Cr, 10% Ni, and 6% Mn, Ti for Automatic Welding. T. M. Slutskaya and S. M. Gurevich. (*Avtom. Svarka*, 1955, **8**, (3), 51–59). Hot cracking is considered and new suggestions for its cause and prevention are advanced. The development of the electrode and flux from these considerations is described and trials on various compositions are reported including the advantages of Ti in the electrode. X-Ray studies showed a single austenitic phase but no columnar structure in the welds. Mechanical properties and analyses of weld metal are given.

Examination of Jesenice Welding Rods and Electrodes in the Light of Yugoslav and International Standards. L. Knez. (*Nova Proizv.*, 1954, **5**, (3–4), 230–239). The products are in general agreement with international requirements.

Experiences Gained with Basic Electrodes in Finland. O. Eiro. (*Schweissen u. Schneiden*, 1957, **9**, Aug., 379–381). The properties of basic electrodes are discussed with reference to welding of boilers and other constructions, including those subjected to the action of sea water. Basic electrodes have good mechanical properties and are not influenced by impurities of the base-material.—B. P.

Methods of Study of the Primary Structure of Welds. A. A. Rossoshinskii. (*Avtom. Svarka*, 1955, **8**, (4), 90–94). A double-etching method using first electrolytic etching in acetate or a solution of HCl–picric acid in alcohol and then HCl–$CuCl_2$–alcohol, the second for 1 sec only, is described and examples of the structures revealed and their meanings are given.

Experiences Gained with the Ultrasonic Method of Testing Welds. R. Hornung. (*Schweisstechn.*, 1957, **11**, Sept., 103–106). The applicability of the ultrasonic method of testing to welded bridges and pipelines is discussed. Test results are illustrated.—U. E.

Contribution to the Study of the Effect of Hydrogen on the Impact Value of the Deposited Metal in Electric Arc Welding with Coated Electrodes. M. Moneyron and D. Séférian. (*Soud. Techn. Connexes*, 1957, **11**, Sept.-Oct., 277–289). Tests are reported to show that the loss of diffusible H_2 of the weld metal at room temperature causes variation of its impact value. N_2 may annul this effect, contributing an ageing factor. (12 references).—B. P.

Some Peculiarities of Intra-Crystallite Heterogeneity and Crystalline Structure of the Weld Metal of Chromium–Nickel Austenitic Steel Type 1Kh18N9. B. A. Movchan. (*Avtom. Svarka*, 1957, (4), 75–82). [In Russian]. The following main conclusions were drawn from this investigation of weld structure in a Cr–Ni austenitic steel: (1) rapid cooling reduces intra-crystallite heterogeneity; (2) sulphur heterogeneity is somewhat increased by a higher Ni content; (3) the columnar crystallites

have a characteristic complicated structure; the large columnar crystallite consisting of a series of elementary crystallites similarly orientated within its boundaries; (4) the enriched zones (segregations) are of appreciable width, occupying 25–30% of the section area and are easily revealed by ordinary metallographic methods; (5) a high-temperature granulation process takes place, leading to a fine crystallographic boundary at the junction of columnar crystals, which may coincide with segregation areas.—S. K.

A Comparison of Methods of Assessing Spot-Weld Ductility in Sheet Steels. Part I. Experimental Investigation. E. J. French and A. A. Wells. (*Brit. Weld. J.*, 1957, **4**, Nov., 514–521). **Part II. Interpretation.** (521–529). Welds in 4 steels of 14 and 18 s.w.g. were examined with low, medium, and high currents and corresponding times. Optimum conditions were not sought. Tensile, shear, hand torsion, Avery machine torsion, B.W.R.A. machine torsion, and sectioning and hardness tests were made. The weld diameter was also measured. Results are tabulated and conclusions drawn. Correlation was marked and hardnesses were usually the same for both gauges and all conditions. In the second part, fractures are illustrated and theoretical strengths and modes of failure evaluated. The effects of ductility ratio are considered and referred to various parameters. Recommendations for the assessment of ductility are given and the tension ratio is suggested as a useful supplement. (17 references).

On the Resistance of Sheet Metal Welds to Strain Ageing. S. Förster, W. Rauterkus, H. Thielmann, and F. Thyssen. (*Schweissen*, 1957, Oct., 447–457). The resistance to ageing of carbon and Mn steels is discussed. Differences between manual, net coated electrode, submerged arc and gas-welding processes are considered. The type of electrode is shown to be important.—R. F.

Weldability as a Function of the Nature of the Material and its Physical State. A. Zapletálek. (*Zvár. Sbornik*, 1957, **6**, (3), 284–312). [In Slovak]. Standard weld-tests carried out on a number of structural carbon steels showed that, quite apart from welding technique, the physical state of a given material as represented by effects of heat treatment and hot and cold working has a definite effect upon weldability.—P. F.

Fatigue and Design in Naval Welded Construction. Z. Garcia Martin. (*Cien. Tecn. Solda.*, 1957, **7**, May-June). [In Spanish]. This subject is discussed, with many examples, under the following headings: (*a*) fatigue tests, (*b*) relation between mechanical properties and fatigue resistance, (*c*) characteristics of fatigue fractures, (*d*) permissible stresses and safety factors, (*e*) nominal stresses and the effect of defects in welded joints, (*f*) stress distribution, (*g*) design considerations, (*h*) importance of the shape of the structure, (*i*) behaviour of riveted and welded structures under fatigue stresses. The latter section is in three parts and discusses butt, angular, auxiliary, and accidental welds in relation to fatigue.—P. S.

A Contribution to the Assessment of Defects in Welds by X-Ray Photographs and Tensile Swelling Tests on Welded Samples. H. Möller and M. Hempel. (*Arch. Eisenhütten.*, 1957, **28**, Sept., 531–541). The effect of welding defects on the strength of metal sheet up to a thickness of 100 mm has been studied. Bonding defects were found to decrease the strength considerably; welds with single pores, groups of pores, or slag inclusions, and re-welded samples had sufficient strength.—L. J. L.

Fish Eyes in Steel Welds. W. Hummitzsch. (*Schweissen u. Schneiden*, 1957, **9**, Aug., 386–390). Fish eyes are said to form in tensile loading stress at maximum load or later. Ultrasonic testing did not show that they formed below or at the yield limit. Therefore fish eyes are of no consequence in structural steels. Hydrogen embrittlement is reduced in time due to loss of hydrogen from the weld area. Fish eyes also tend to disappear in time.

Structural Defects of Austenitic Welds in Ferritic Steels Subjected to High Temperatures. F. Erdmann-Jesnitzer, M. Beckert, and H. Schmiedel. (*Schweissen u. Schneiden*, 1957, **9**, Sept., 407–414). The decarburization due to up-hill diffusion in the adjacent zone of an austenitic weld in ferritic steel is examined. An apparatus is described with which to determine the depth of the decarburized zone-time behaviour up to fracture due to stress corrosion. The causes for intercrystalline cracking occurring in the fine-grained intermediate zone are discussed. (50 references).—U. E.

Influence of Flux Composition on the Distribution of Phosphorus between Slag and Seam Metal. V. V. Podgaetskii and L. A. Poznyak. (*Avtom. Svarka*, 1957, (4), 15–18). [In Russian]. In the investigation described the influence of flux composition on transfer of phosphorus from flux to metal was studied. Transfer was greater when silica and MnO in the fluxes was low. When the flux contained less than 15% SiO_2 and Al_2O_3, dephosphorization of the bath metal occurred. Using radioactive P it was shown that with a high-silica manganese flux (AN-348-A) and a low-silica manganese-free flux (AN-20), phosphorus transfer to the slag is practically non-existent. The nature of phosphorus distribution is considered to depend on the form in which oxygen is contained in the slag, ionic or as silicate or aluminate ions.—S. K.

Microcracking in Mild Steel Weld Metal. K. Winterton. (*Can. Metalw.*, 1957, **20**, Sept., **34**, 36, 38–40, 42). Cracks show up mainly on longitudinal sections and require special polishing and etching methods. They are associated with hydrogen content and arise from rapid cooling rates at low plate temperatures. Previous work is reviewed and tests on rolled mild steel are described and cracks are illustrated. A theory is advanced in terms of H_2 accumulation in pre-existing flaws. Tests with various electrodes are described and cracking is related to H_2 content and to other inclusions. Weld hardness did not correlate. Five types of inclusions are distinguished, the most important for crack production being rhodonite with free silica.

Segregation in the Fusion Zone and in Solidification Layers as Related to the Diffusion between Solid and Liquid Phases in the Freezing of Welds. A. M. Makara and A. A. Rossoshinskii. (*Avtom. Svarka*, 1956, **9**, (6), 65–76). A review of previous work is given, and an account of a study of the layers formed and the processes of diffusion in welds. Segregation was found to occur directly during welding and the coexistence of solid and liquid phases was found to be the cause owing to the processes of diffusion occurring. A periodicity occurs in solidification owing to liberated latent heat.

Some Problems of the Formation of Crystallisation Cracks in Electric Slag Welding. S. A. Ostrovskaya. (*Avtom. Svarka*, 1957, (4), 33–47). [In Russian]. An account is given of a comprehensive experimental investigation of the nature of the distribution and reasons for the formation of crystallization cracks in the seam metal produced by electric welding under flux of carbon structural steels. Cracks obtained under various conditions are illustrated and discussed. Experiments on the influence on resistance to crystallization-crack formation of the chemical composition of the weld metal and of the direction of primary crystallization are described and considered. It is concluded that for a good resistance against crystallization, cracking with increasing carbon-content in the base metal the electrode-wire feed rate or the number of electrodes must be reduced.—S. K.

Influence of Titanium on Reduction of the Tendency of Deposited Metal to Hot Cracking. E. I. Leinachuk. (*Avtom. Svarka*, 1957, (4), 52–58). [In Russian]. In the investigation described the influence of Ti on the liability of metal containing 0·50–2·98% carbon welded on steel to hot cracking was studied. It was found that when the Ti content was increasing the liability first decreased and then started increasing again. Under the experimental conditions used, hot cracks were absent when the deposited metal contained 0·50–0·75% C and 0·51–1·89% Ti and also 1·1–1·2% C and 0·86–1·8% Ti. Metallographic investigation showed that Ti disrupts the columnar structure of the deposited metal and combines with carbon as carbides, these being evenly distributed with medium contents of Ti and unevenly with high contents of this element.

Rationalisation in Flame Soldering. H. H. Grix. (*Schweissen u. Schneiden*, 1957, **9**, Aug., 381–385). The author discusses the suitability of solders and soldering fluxes, taking economic considerations into account. Silver solders permit the use of automatic or semi-automatic soldering devices, thus reducing costs in spite of the higher silver content required.—R. F.

Brazing for High Temperature Use. G. S. Hoppin. (*Steel*, 1957, **141**, Aug. 26, 82–86). Difficulties associated with brazing with nickel base alloys for applications up to 2000° F are considered, and examples of successful applications are given. Brazing is done in furnaces with purified (dry) H_2 atmospheres; vacuum brazing is being developed. Erosion troubles are minimized with B-free alloys; brittleness may be reduced with high temperature annealing.—D. L. C. F.

Observations on the Bonding Mechanism in Braze Welding. H. Granjon. (*Soudage et Techniques Connexes*, 1957, **11**, July/Aug., 247–254). The author discusses the bonding mechanism in braze-welding of ferrous materials, using silicon brass as filler metal. The weld metal can be dissolved in nitric acid. Subsequent examination of the structure shows that bonding has taken place by infiltration at the ferrite grain boundaries followed by diffusion into the austenite.

On the Mechanical Hot Cracking of Welds. V. A. Toropov. (*Metallovedenie Obrab. Met.*, 1957, **3**, June, 54–58). After a survey of theories, work is reported tending to show that hot cracking depends upon the course of solidification of the intergranular substance. The possibilities of reducing the susceptibility by altering the amounts and compositions of the intergranular phase are discussed.

Mechanism of Microcracking in Mild Steel Welding. K. Winterton. (*Welding J.*, 1957, **36**, Oct., 449s–456s). The effect of several variables on incidence of microcracking has been examined and discussed. A general theory is put forward to account for microcracking (and halo-formation) in terms of the accumulation of H_2 under pressure in pre-existent flaws, especially incipient hot cracks. The phenomenon of H_2 diffusing out of weld metal is illustrated.—U. E.

A New Type of Brazing Furnace. (*Weld. Met. Fab.*, 1957, **25**, Dec., 469–471). A design working to above 1250° C in a controlled atmosphere is described based on a refractory developed by Kepston Ltd. It is expected that a vacuum type will be produced.

Cold Retort Furnace Brazes High-Temperature Honeycomb. R. R. Giler. (*Iron Age*, 1958, **181**, Jan. 16, 74–75). A vacuum furnace —the Westinghouse Kold—Retort—is described. The shell is water-cooled and shielded from the heat of the internal elements.

Thermal Analysis of Brazing and Hard-Surfacing Alloys—A Proposed Method. F. M. Miller. (*Welding J.* 1957, **36**, Oct., 986–991). Melting characteristics of brazing and hard-surfacing alloys have been investigated by means of a novel procedure which is described.

MACHINING AND MACHINABILITY

Metal Cutting Research: Activities of the Production Engineering Research Association. (*Iron Steel*, 1957, **30**, Dec., 647–651). A short survey is made of researches into cutting tools carried out by P.E.R.A., and examples of research results are given. Reference is also made to investigations into machine tools and cutting fluids, and attention is given to drilling to illustrate the scope of research in a particular field.—G. F.

Metal Cutting Research and Drilling Technique. (*Mech. World*, 1957, **137**, Dec., 539–543). The work of the Production Engineering Research Association is reviewed.

Experimental Study on the Combined Influence of the Sharpening Angle of the Tool and of the Cutting Speed on the Modalities of Chip Formation. E. Eugène. (*Microtecnic*, 1957, **11**, (5), 223–230). Studies by instantaneous photography are reported on various electric arc and O.H. furnace steels, and the

mechanism is indicated and the effects of angle and speed deduced.

An Easier Way to Find Best Cutting Speed. H. J. Siekman. (*Metalw. Prod.*, 1958, **102**, Feb. 28, 365–368). An equation for tool life giving minimum cost per piece and another for tool life for maximum production are developed and converted to cutting speeds from a chart.

Studies on Built-up Edge Formation in Metal Cutting. M. Okoshi and T. Sata. (*Rep. Sci. Res. Inst.* 1957, **33**, May, 155–164.) (In Japanese].

Studies on Surface Finish in Fine Turning. M. Okoshi, T. Sata and A. Kamogawa. (*Rep. Sci. Res. Inst.* 1957, **33**, July, 209–227).

Efficient Milling with Shank Tools. (*Machinery Lloyd*, 1958, **30**, Feb. 22, 47–52). Many data on rotational speeds, cutter diameters, and optimum feeds are presented.

Researches on the Sintered Carbide Face Milling Cutter. I: On Cutter Wear. II: Power Consumption and Cutting Force. III: On the Effect of Double Radial Rake. M. Okoshi and N. Shinozaki. (*Rep. Sci. Res. Inst.* 1957, **33**, May, 137–154; July, 185–198; 199–208).

Development and Testing of Tungsten Carbide Tipped Drill Steels.—I. Development of Integral Drill Steel. C. Dahlin. (*Chem. Eng. Min. Rev.*, 1957, **49**, Sept. 16, 38–43). **II. Testing of Drill Steels.** (Oct. 15, 48–53).

Increasing the Life of Stationary Mandrels in Piercing Mills. Ya. S. Finkel'shtein and T. S. Shchegol'. (*Stal'*, 1957, (12), 1099–1103). Mandrel life can be improved by imparting a stable austenitic structure to the Mn steel from which they are made. This is achieved by rapid quenching. Optimum design for long life mandrels is a streamlined shape with a cylindrical nose. Correct alignment of rolls and positioning of mandrels and abundant cooling between piercing operations also help to reduce mandrel consumption by 80%.

Tips on Turning Heat-Treated Steels. (*Steel*, 1957, **141**, Nov. 25, 94–95).

Ultra-Finishing, A New Process of High-Precision Grinding. (*Usine Nouv.*, 1956, **14**, Jan. 23, 37–38; *Machine Moderne*, 1957, June, 41). A method of finishing to 0·3–0·5 micro-in (7·5–12·5 μ) is described, using an abrasive on cloth over a 12 mm block of pitch on a suitable support.

Physical Properties of Hard Metals as a Function of the Carbon Content. R. Bernard. (*Neve Hütte*, 1957, **2**, Dec., 757–761). The part played by cobalt in hard alloys is emphasized. The fundamental importance that attaches to carbon within the micro-crystal structure and the physical and chemical properties of the alloy in the Co-enriched phase are discussed.—L. J. L.

The Influence of Microstructure on the Machinability of a Medium Carbon Steel. A Gibson. (*Aust. Mack. Prod. Eng.*, 1957, **10**, Dec., 13–18). Medium carbon steel bars were normalized and annealed under various conditions. Tool life and cutting-force tests were carried out on these and on control bars from the same heat. The optimum structure for machinability is a pearlite-ferrite structure with lamellar and spheroidal pearlite. Banded structures and large grain sizes are to be avoided. It may be economical to heat-treat material to obtain the more machinable structures.

Machinability of Cold Drawn Steel Bars. F. J. Robbins. (*Western Metalw.*, 1957, **15**, Dec., 47–49). Cold finishing (cold drawing, turning and polishing and grinding and polishing) improves finish, size, and concentricity, mechanical properties and machinability. The importance of the relationship between tensile strength and ductility is discussed. The effects of Mn, P, S and Pb on machinability are reviewed.—R. S.

Cutting Fluid Selection. (*Met. Prog.*, 1958, **73**, Feb., 102–103). A short survey showing factors involved in the ordering of cutting fluids is presented. 239 plants replied to the questionnaire.—R. G. B.

Principles and Applications of Spark Machining. D. W. Rudorff. (*Proc. I.M.E.*, 1957, **171**, (14), 495–511).

Electronic Control of the Spark Machining Process. D. T. Vasil'ev. (*Stanki Inst.*, 1947, **18**, (5), 1–5). A formula for the cutting capacity of the process is given and a method of control is described. The advantages of the multiple-electrode process are given and extension of the method is recommended.

Applications of Electrolytic Grinding. C. R. Stroup. (*Metalw. Prod.*, 1958, **102**, Feb. 28, 370–373). The equipment necessary is described, conventional grinding machines can usually be modified to use the process. Examples are listed and a few are illustrated.

Photoetching Forms Thin Parts. (*Steel*, 1957, **141**, Nov. 18, 153–156). The process and applications of the photoetching technique for metalworking intricate and fragile parts are described. The process involves making a drawing of the part, which may be many times finished size, photographing this and printing the image on treated metal which can be processed so that a hardened emulsion mask remains; the exposed portion can then be acid-etched away.—D. L. C. P.

The Cutting of Round Wire with Knife-Edge and Flat-Edge Tools. W. Johnson. (*Appl. Sci. Res.*, 1957, **7A**, (1), 65–88). Cutting of galvanized and straight-drawn medium carbon steel wires, special hard steel and Cu are studied.

The Story of Shot Peening. G. Leghorn. (*J. Am. Soc. Naval Eng.*, 1957, **69**, Nov., 653–666). A review of the process, apparatus used and effects produced, with special reference to fatigue strength. 95 uses for straightening parts, preventing stress corrosion cracking and eliminating fretting corrosion are also noted, and in removing grinding defects, correcting casting porosity, deburring, decorative texturing and in testing plating adhesion. Variables still not investigated are pointed out.

An Experimental Investigation into the Characteristics and Behaviour of the Built Up Nose When Machining Mild Steel with High Speed Steel Tools. W. B. Heginbotham. (*Microtecnic*, 1957, **11**, (3), 113–121). A study of the transition from simple shear to the built-up nose condition is reported. An arrangement for abrupt stopping of the lathe is described. On stopping (in 0·00048 sec) the nose was found to have adhered to the tool and to the underside of the chip. Structures are shown and mechanisms considered, and criteria for nose build up established.

Experimental Study of the Mechanism of Plastic Deformation in Metal Cutting Compared with the Methods of Classical Stressing. P. Bastien and M. Weisz. (*Microtecnic*, 1957, **11**, (3), 122–131; (4), 151–162). Experimental comparisons with cutting and the traction and torsion tests are reported.

Shear-Zone Temperature in Metal Cutting and its Effects on Shear-Flow Stress. D. Kececioglu. (*Trans. ASME*, 1957, preprint 57-SA-70, pp. 7). Equations giving mean shear-zone temperature in oblique and orthogonal cutting are derived. The mean temperature developed in machining SAE 1015 118Bn seamless tubing varies from 410–840° F under a wide range of conditions. Mean shear-flow stress is examined and found to decrease by — 1800 psi per 100° F increase in the 410–840° F range. A more comprehensive approach is proposed.

Experimental Measurement of Metal-Cutting Temperature Distributions. G. S. Reichenbach. (*Trans. ASME, reprint*, 57-SA-53, 1957, June, pp. 15). A radiation method using a photocell and a thermocouple process using an embedded wire are described. Temperature fields measured were in only fair agreement with theory owing to the approximations used. A conducting paper electrical analogue is described.

Effect of Residual Stresses in Hardened Tool Steels on the Formation of Fissures in Grinding. H. Bühler and W. Schepp. (*Stahl u. Eisen*, 1957, **77**, Nov. 14, 1686–1690). Tests on cylinders of two tool steels show that water-quenching from various temperatures introduces internal stresses which may lead to fissuring in grinding if the internal stress is caused by a tensile stress gradient in the outer zone.—T. G.

The Effect of Phosphating in Improving the Effectiveness of Cutting Tools. B. Lanyi. (*Proc. Conference on Electrochemistry* 1955, *Warsaw*, 1957, 527–529). [In German]. Two baths for phosphating are given and drilling tests are reported.

The Economics of Roll Machining. H. Warrol. (*Jernkont. Ann.*, 1957, **141**, (11), 798–803). [In Swedish]. In the rolling of wire rod, ground rolls were found the better. The advantage is probably greater for rolls with high surface hardness.

Influence of Various Factors on the Quality of the Surface in Turning Cast Iron. N. P. Golybov. (*Vestnik Mashin.*, 1957, (8), 64–65). [In Russian]. In turning high-strength cast iron, the increase in the rate of feed does not influence the quality of the working surface if the width of the cutting edge is 1·2 to 1·5 times the feed.—L. H.

The Wear of Ceramic Cutting Tools in the Fine Boring of Cast Iron. V. A. Kacher. (*Stanki i Instrument*, 1957, (4), 25–26). [In Russian]. The composition of the cast iron on which these tests were carried out was: 3·37% C, 0·60% Mn, 2·20% Si. 0·17% P, 0·11% Cr, 0·11 S, and 0·12% Ni. Hardened at 830°, tempered at 220°. The cutting tool was the TsM332 cutting plates of two types of steel. The results of these tests are tabulated for the different rates of cutting. The conclusions reached were that the wear of these tools for a suitable cutting process and suitable geometry of the cutters should not exceed 0·5–0·6 mm for an accuracy of the 6th to 7th order with a speed of 75–105 mm/min.

The Use of the Hard Alloy VK 2 for Roughing Operations with Cast Iron. A. B. Novikov. (*Stanki i Instrument*, 1956, (3), 18). [In Russian]. The alloy VK 2 is superior to all other alloys of the tungsten group in heat resistance and in hardness to wear. It is here experimentally compared with another alloy VK 8, and the tabulated findings confirm its superiority.—L. H.

What Angles Are Best for Ceramic Tools? H. J. Siekmann and L. A. Sowinski. (*Metalw. Prod.*, 1957, **101**, Sept. 6, 1573–1575). Optimum tool geometry for ceramics differs from that of carbide tools. Rake, edge-cutting angles, and nose radii are investigated.

Hard Metal Alloys With Low Auxiliary Metal Contents. C. Agte and R. Kohlermann. (*Giesserei*, 1957, **12**, Oct., 686–689). A table is presented listing some of the wear-resistant hard metals available for the production of cutting tools. Previous methods of producing hard metals are critically examined; some experiments are described and results reported, and the qualities of two hard metals containing respectively 73·5% WC, 24·0% TiC + (TaC, NbC, VC) and 97·5% WC are noted.—L. J. L.

Development and Testing of Cemented Tungsten Carbide Tipped Drill Steels. C. Dahlin. (*Bull. School Mines Met. Univ. Missouri*, 1957, (94), 67–92). The development of integral drill steel, its structure and properties is outlined and the evolution of drilling test methods described. Statistical treatment of the results is given.

Drive of Spark-erosion Machines. G. Hoffmeister. (*V.D.I.Z.*, 1957, **99**, Sept. 21, 1317–1318). The chief process variables of spark erosion are discussed together with their influence on the rate of working and surface finish.—J. G. W.

Electro-Erosion Device for Hard Metal Dressing. S. Fele. (*Elektrotech. Vestnik*, 1957, **25**, (7–8), 259, 277–279). [In Serbo-Croat]. A comparatively cheap version of the American X-process machine, operating on the spark discharge principle, was developed by the author. Circuits are given.—P. F.

Metallurgical Processes During Grinding of Steel. H. Staudinger. (*Schweiz. Arch. Wiss. Techn.*, 1957, **23**, July, 231–240). The author discusses the principles of grinding hardened steels and the structural surface changes which occur during grinding. He goes on to explain surface defects caused by bad grinding techniques. Suggestions are made for avoiding defects and undesirable changes. (20 references).—R. P.

Turning or Grinding Roll Grooves: A Comparison. T. Palm. (*Jernkont. Ann.*, 1957, **141**, (11), 790–797). [In Swedish]. An investigation on chilled rolls showed the surface quality of a ground roll to be higher than that of turned roll. The difference soon disappears in use and surface quality then remains practically constant. It is wear of the groove and not impaired surface quality that eventually determines the life of the roll.

The Use of CO_2 in the Grinding of Steels Machinable with Difficulty. N. P. Sobolev and A. M. Z. Valitov. (*Stanki i Instrument*, 1956, (3), 18–19. [In Russian]. Steels K and 45 were investigated concerning the temperature of cutting, the chips, the variations in the coefficient of friction, the force of cutting, the wear and the resistance of the cutters, the mechanism of cutting and the cleanliness and hardness of the working surface. The investigations showed that the greatest advantage in the use of CO_2 resides in the possibility of increasing productivity in the cutting process.

Mechanization Cuts Slab Grinding Cost. H. R. Kerber. (*Steel*, 1957, 141, Sept. 2, 138–144). Characteristics of mechanical slab grinders are explained and operating techniques described. The method has advantages over manual operation in spite of rapid wheel wear.

Quality of the Surface and Uniformity of Removal of Metals with Fluid-Abrasive Polishing. Sh. M. Bilik. (*Stanki i Instrument*, 1957, (1), 16–20). [In Russian]. Comprehensive tests are described on polishing with abrasives of various grain sizes and concentrations, with varying nozzles and sprayers and with varying times for the operation. Results of these comprehensive tests are tabulated and graphically recorded.—L. H.

The Use of Shot Peening to Reduce Weight. W. R. Berry. (*Proc. I.M.E. Auto. Div.*, 1955–56, No. 7, 219–232). Tests on silico-manganese spring steel are reported. Scragging is also considered and weight savings of 20–25% appear possible.

Damage by Uncontrolled Shot Blasting. K. Kornfeld. (*Met. Prog.*, 1958, **73**, Feb., 92). Two examples are shown of fatigue cracks developing as a result of shot blasting.

CLEANING AND PICKLING

When to Use Solvent-Vapor Degreasing. C. E. Kircher. (*Met. Fin.*, 1957, **55**, Dec., 63–64, 66). Factors affecting the application of trichlorethylene are discussed.—A. D. H.

Pickling Stainless to Remove Scale. W. E. McFee. (*Steel*, 1957, **141**, Nov. 25, 103–107). Methods of cleaning stainless steel under various circumstances are described. Seven pickling treatments are specified.—D. L. C. P.

Chemical Surface Preparation of Structural Steel After Erection. C. D. Coppard, J. H. Lawrence, F. S. Bricknell and H. W. Adams. (*Corrosion*, 1957, **13**, Nov., 141–142). An extract from an article describing descaling jellies developed in Britain for use on structural steel on site. The properties of hydrochloric acid, sulphuric acid and, particularly, phosphoric acid jellies are described.—J. F. S.

Chromic Acid Rinse Treatment. S. L. Eisler. (*Ind. Fin.*, 1957, **9**, Sept., 818–821). The amount of chromic acid adsorbed on phosphated steel was studied by using a radio-isotope of chromium. Cr adsorption varies directly with concentration and is increased by the presence of phosphoric acid. Only slight desorption occurs in hot or cold water; trichlorethylene is without effect. The optimum solution strengths are Cr_2O_3 30 oz./100 gal. or Cr_2O_3 16 oz, H_3PO_4 16 oz/100 gal.

American Practice in Stainless Steel Finishing. (*Ind. Fin.*, 1957, **9**, Nov., 930–934). Details of mechanical polishing methods currently used in U.S.A. are described.

Which Abrasives for Barrel Tumbling? C. Mathewson. (*Metalw. Prod.*, 1958, **102**, Feb. 21, 322). Tests on standard blocks of steels and other metals are noted, bringing out the advantages of manufactured abrasives over granite chips.

The Finishing of Parts Achieved in Drums with Abrasives. J. Pischzek. (*Tecn. Met.*, 1957, **13**, Jul.–Aug., 164–167.) [In Spanish.] The principles and advantages of this method of cleaning and producing fine surfaces are detailed. Abrasives, cleaning agents and the steps in the process are also described.—P. S.

Mechanical Descaling of Rolled Products. J. Kostkuba. (*Hutník*, 1957, **7**, (7), 226–230). [In Czech]. Foreign makes of descaling equipment used mainly for steel bars and rods are reviewed. It is concluded that mechanical descaling is more economical than pickling.

Mechanical Descaling and Drawing of Mild Steel Rod. L. Marsden. (*Award Paper, Fred Smith & Co. Staff School*, 1956; *Wire Ind.*, 1957, **24**, Nov., 1039–1046). An account is given of the mechanical descaling installation at J. & A. Binns Ltd., Halifax, and of its operation, with reference to developments elsewhere. Preference is expressed for the rotating brush type of descaler and the importance of soap pick-up is stressed; optimum results were obtained with a first block speed of 200 f.p.m. Rods must not be weathered, but should be aged in a dry atmosphere for about 48 h. A lime-based granulated soap was found necessary and pressure lubrication seemed to improve matters. Die life and machine efficiency were found to be excellent.—J. G. W.

Abrasive Blast Cleans Weldments. (*Steel*, 1957, **141**, Dec. 23, 78). Several reports are cited which indicate that the cleaning of welded parts by abrasive blast may be fast, penetrating and economic while improving quality.—D. L. C. P.

An Improved Method of Flame De-scaling for Spot Welding. M. Evrard. (*Brit. Weld. J.*, 1958, **5**, Feb., 57–65). Flame heating and water cooling has been developed as a process for scale removal using statistical methods to reduce the number of tests required. Spot welds of good quality are then obtainable. Comparisons with other methods and use for other purposes are also discussed.

Descaling Line Cuts Stock Costs. (*Iron Age*, 1958, **181**, Jan. 23, 86–87).

Kinetics of Scale Disintegration When Etching Stainless Steel in Nitric Acid. A. I. Matantsev. (*Stal'*, 1957, (12), 1118). In nitric acid solutions at high temperatures, maximum speed of disintegration of scale on 18/9 Cr–Ni–Ti steel and 18/9 Cr–Ni steel and gas formation are displaced towards lower concentrations. The relationships between the speed of scale break-up and the concentration and temperature of the acid are discussed.—R. S.

Electrolytic Polishing of Stainless Steel. P. F. McKinney. (*Chem. Proc. Eng.*, 1958, **39**, Feb., 59–60). Especial attention to uses in the chemical industry is given.

PROTECTIVE COATINGS

Developments in Swedish Electroplating Practice During the Past Two Years. G. Jonsson. (*Met. Fin. J.*, 1958, **4**, Jan., 11–16, 26). With illustrations of automatic installations.

Investigation of the Electrodeposition of Metals on Passivated Surfaces. L. I. Kadaner and A. Kh. Masik. (*Zhur. Fiz. Khim.*, 1956, **30**, (9), 1983–1989). Studies by microcrystallography, X-rays, tracer studies with ^{35}S and measurements by static and oscillographic methods of change of potential with time led to a mechanism for electrodeposition on passivated surfaces. It is shown that initially the film is partly reduced and this frees a larger area than do the usual pre-plating processes. A large number of small crystals is formed so that greater integrity, better corrosion-resistance and superior adhesion result.

Automatic Loader Speeds Plating of Auto Parts. R. L. Everstine. (*Products Fin.*, 1958, **22**, Jan., 36–41). A completely automatic elevator-type conveyor system is described and illustrated. It handles 50 loads of parts per h. through a double (Ni, Cr) plating operation, involving 30 separate immersions in 2 h. 12 min., transfer time between tanks is 40 sec.

Microthrowing Power. E. B. Leffler and H. Leidheiser jun. (*Plating*, 1957, **44**, Apr., 388–396). A review from a literature survey. (46 refs.).

Further Studies of an Electronic Thickness Gauge. F. P. Brodell and A. Brenner. (*Plating*, 1957, **44**, June, 591–601). A device depending on the skin effect and known as the Dermitron is described. Measurements on Ni coatings were unreliable.

Effluent Problems. F. Wild. (*Met. Ind.*, 1958, **92**, Jan. 24, 69–71); **II. Chemical Treatment.** (Feb. 7, 111–113). Legal aspects and treatment of plating effluents are outlined. **III. Plant Layout and Construction.** (Feb. 21, 153–155). Principles are outlined in general terms and flow sheets shown.

Cyanide Waste Oxidised in the Plating Room. E. A. Hill and F. J. Neff. (*Plating*, 1957, **44**, Aug., 864–868). The alkaline chlorination process is described.

Current Trends in Plating Waste Abatement. C. F. Gurnham. (*Plating*, 1957, **44**, Aug., 873–878).

Low-Cost Integrated Waste Treatment at American Steriliser. J. Stroh and C. Allen. (*Plating*, 1957, **44**, Aug., 869–872). Chromium plating waste is dealt with as well as cyanides.

Operating Experiences with Chromic Acid Recovery Equipment. C. L. Gough and C. G. Bueltman. (*Plating*, 1957, **44**, Aug., 879–883). Ion-exchange methods were used.

How to Dispose of Cyanide Plating Wastes. B. H. Robbins. (*Iron Age*, 1957, **180**, Nov. 28, 92–94). Disposal of solid and liquid cyanide-bearing wastes from copper and zinc plating operations at an Oldsmobile plant is described. NaClO treatment is used.—D. L. C. P.

Hardness of Chromium Plating. N. P. Fedot'ev. (*Ind. Fin.*, 1957, **9**, Oct., 888). A summary of recent work by the author is made. Micro-hardness measurements on coatings $5 \pm 0{\cdot}5\ \mu$ in thickness showed that for each value of current density in the range 10–500 amp. dm^{-2} a max. and min. value of hardness occurred as the temperature increased in the range 25–85° C. With increasing current density the max. and min. values were displaced towards higher temp. where the absolute max. was increased and the min. decreased.—A. D. H.

Unconventional Chromium Plating. J. B. Mohler. (*Met. Fin.*, 1957, **55**, Dec., 75–76). The characteristics and operation of the chromic-sulphuric acid plating bath are presented.—A. D. H.

Effects of Tempering on the Mechanical Properties of Chromium-Plated Steel Parts. V. S. Borisov and F. N. Naumov. (*Metallov. Obra. Met.*, 1956, (12), 50–56). A study of low-temperature tempering of two steels before and after chromium plating is presented. Tensile, impact and rotating bend tests were carried out. In general only fatigue strength was appreciably impaired. Internal stresses are regarded as more important than hydrogen absorption.

Diffusion Process Makes Plain Carbon Sheet Stainless. (*Iron Age*, 1957, **180**, Nov. 7, 128–129). The advantages of stainless-surfaced steel produced by the "Chromallizing" process are described. The Cr diffusion method produces carbon steel with an integral stainless surface, which will withstand operating temperatures of 1200–1500° F. The cost of Chromalloy-Stainless is one-third to two-thirds that of solid stainless sheet. High carbon steel and Mo have also been Chromallized.—D. L. C. P.

Pack Chromising Method Hikes Heat, Wear, Corrosion Resistance on Varied Components. M. C. Commanday. (*Western Metalw.*, 1958, **16**, Jan., 46–48). Chromous iodide is used as a carrier gas in the pack process. Its application to cast iron moulds used for making glassware is described. The diffusion of chromium into ferrous metals under various conditions is discussed.—R. S.

Some Aspects of Zinc, Copper, Nickel and Chromium Plating. L. Ades. (*Met. Fin. J.*, 1957, **3**, Dec., 477–484, 496). Work on Zeromist, which actually slightly increases the throwing power of Cr baths, on sulphamic acid in Ni, Cu and Cd plating, on the Zn plating of cast iron, alkaline Cu baths and the effect of impurities in bright Ni plating is reported.

Nickel Sulphamate Plating. E. Calderon. (*Prod. Fin.*, 1957, **10**, Dec., 81–83, 116. A

general account of the chemistry of the process, the bath used and the deposits produced is given.

Improvement in the Oxidation and Wear Resistance of Nickel Coatings. A. Portalupi and E. Melgara. (*Mét. Constr. Mécan.*, 1956, **88**, Sept., 747–753). The properties of nickel coatings deposited electrically and chemically are compared.—B. G. B.

Throwing Power in Elco-Udylite Bright Nickel Solutions. P. Meuldijk. (*Met. Fin. J.*, 1957, **3**, Dec., 491–492, 494). Tests are described. No great variations in throwing power were noted though certain trends are indicated.

Accidental Contamination of Bright Nickel Solution. J. Corbiere. (*Met. Fin. J.*, 1958, **4**, Jan., 24–25). Phosphoric acid was added in error. The regeneration of the bath was effected. It was noted that the effect of Al was similar.

New Stripping Solution for Phosphate Coatings. S. L. Eisler. (*Ind. Fin.*, 1957, **9**, Oct., 878, 880, 883, 885, 887). The efficiency of solutions containing NaOH, sodium cyanide and the sodium salt of E.D.T.A. for removing phosphate coatings was determined by the use of a radio-isotope of phosphorus. A solution containing NaOH 24 oz/gal NaCN 12 oz/gal removed zinc and iron phosphate coatings in 10 min at room temperature and only a slight improvement was obtained with E.D.T.A. For manganese phosphate it was necessary to heat the solution to 160° F and make the work cathodic. Rephosphating was unaffected by a previous stripping treatment.—A. D. H.

Synthetic Rubber Products for Protection against Corrosion. S. Reiner. (*Werks. Korr.*, 1958, **9**, Jan., 1–4). Synthetic polymers, their resistance to various materials in the chemical industry, and their application and testing are reviewed.

Epoxy Coatings: Performance and Application Data. F. Grushoff. (*Products Fin.*, 1958, **22**, Jan., 42–47). Resistances to various chemicals are also given.

Epoxy Coatings Perform Well on Steel Exposed to Chemicals, Corrosive Atmospheres. W. M. Brackett. (*Corrosion*, 1957, **13**, Nov., 144–146). A summary of a paper giving case histories of the successful use of epoxy coating systems on steel exposed to chemicals and corrosive atmospheres. The coating of petrol and solvent storage tank exteriors, paper mill tanks and other structural steelwork is described and good performance up to five years is reported.—J. F. S.

Porcelain Coatings on Steel. L. E. Fussell and H. P. Tripp. (*Prod. Eng.*, 1958, **29**, Feb. 17, 75–77). Lower firing temperatures and enamels for one-coat use on ordinary cold-rolled steel can now be attained. Effect of temperature on properties and coating defects and their cures are set out.

Enamels for Metals. J. H. Handwerk and T. N. McVay. (*U.S. Atomic Energy Commission, Tech. Inf. Service, ORO-47*, 1951, Oct. 24, pp. 92). Enamels for the shielding of nuclear reactors were studied. They are classified as containing BaO, PbO, Li_2O and CdO, and the effects of basic oxide and the properties of laminated enamel-iron structures are also discussed. Some preliminary high-temperature resistance studies are added. A standard enamelling procedure by spray on caustic-pickled iron plates was used, and visual examination of colour, texture and gloss, thickness measurement by "Elcometer" and a bend adhesion test were carried out.

Coatings for the Protection of Low Carbon Steel at Elevated Temperatures. J. H. Handwerk and T. N. McVay. (*U.S. Atomic Energy Commission, Tech. Inf. Service, ORO-79*, 1952, Nov., pp. 33). Additions of refractory materials to sheet iron ground-coat enamels were used, such as Cr_2O_3 and Al_2O_3. The latter were superior at high temperatures and served up to 1400° F for 100 h. They also withstood flame impingement tests at 1620–1650° F for 2 h.

The Stress-Optical Test in the Enamel Factory. H. J. van Buren. (*Inst. Vit. Enamel. Bull.*, 1958, **8**, Jan., 36–37).

Enamel on Stainless: Combination for Strong Walls. (*Iron Age*, 1957, **180**, Dec. 5, 139). The building panels described consist of an enamelled stainless steel facing, an aluminium honeycomb core, and an electrogalvanized mild-steel backsheet, bonded together with a thermoplastic adhesive.

Effect of Firing Schedules on Stress-Temperature Relations in Enamel-Metal Systems. J. H. Lauchner, R. L. Cook and A. I. Andrews. (*J. Am. Ceram. Soc.*, 1957, **40**, Dec., 410–415). The thermal deflection of enamelled iron strips was examined and related to firing schedule and coefficients of expansion were calculated and found to agree with interferometer measurements. Variation of cooling rate produces marked changes in stress. Residual compressive stresses are increased by rapid cooling and tensile stress developed during reheating is reduced by previous annealing.

An Introduction to Wash Primers. E. S. Beck. (*Met. Fin.*, 1958, **56**, Jan., 58–60; Feb., 61–64). Exposure tests are illustrated on steel panels with or without phosphate treatment with enamel coatings over wash primers. Formulations are discussed and uses noted.

POWDER METALLURGY

Powder Metallurgy. I. Jenkins. (*Metallurgia*, 1957, **56**, Dec., 271–275). An elementary account of the production and applications of engineering components made by powder metallurgical methods.—A. D. H.

Report on Powder Metallurgy in the U.S.S.R. H. H. Hausner. (*Met. Prog.*, 1958, **73**, Jan., 105–108). A short review of the research organization and recent developments in powder metallurgy in Russia is presented.

Some Theoretical and Practical Problems of Powder Metallurgy in the Soviet Union. W. S. Rakowski. (*Neue Hütte*, 1957, **2**, Dec., 764–767). A description is given of: (1) radioactive tracer methods to study the sintering process, (2) the application of ultrasonics to the sintering process, and (3) production processes and properties of new products of powder metallurgy, *e.g.* friction materials on an iron base, and sintered iron friction bearings for rolling stock.—L. J. L.

How to Give Powdered Metals Strength. (*Steel*, 1957, **141**, Nov. 25, 110–114). The infiltration method of impregnating powdered metal parts is described. Compacts of the base metal and Cu are formed conventionally. The compacts are placed together and passed through a protective atmosphere furnace so that the Cu melts and is taken into the pores of the iron or steel compact. Physical properties of the product can be controlled by varying the conditions and materials used.

New: Pre-Alloyed Metal Powders. P. R. Mallory & Co. Inc. (*Prec. Met. Mold.*, 1958, **16**, Feb., 35–36). Stainless steel and Fe–Mn–Ni and Cu–Ni–Fe powders are available for high-density sinterings. The properties of compacted powders are compared with those of wrought alloy steels.

Making Strip Metal from Metallic Powder. W. N. Hayden, J. D. Shaw and W. V. Knopp. (*Prec. Met. Mold.*, 1958, **16**, Jan., 48). A pilot plant with a capacity of 4-t per day has been constructed, so far on Cu, but iron and stainless steel powders can be used.

Sintered Metals Approach Properties of Wrought Alloys. (*Iron Age*, 1958, **181**, Jan. 23, 88–90). Compositions and properties of "Steelmet" products of P. R. Mallory & Co. Inc. are given. These powdered iron and steel alloys can be pressed and sintered to form gears, cams, levers, pawls, ratchets and many other parts for high stress applications, with advantages over machine-wrought articles. The powders can be pressed at 30 to 50 t/in², and give sintered products with densities above 95% of theoretical.

Using Sinterings Raised Part Life 400%. S. Bangs. (*Prec. Met. Mold.*, 1958, **16**, Jan., 43). Parts for a chain saw were made of sintered iron powder.

An Investigation of the Slip-Casting Mechanism as Applied to Stainless Steel Powder. W. G. Lidman and R. V. Rubino. (*U.S. Atomic Energy Commission, Tech. Inf. Service Extension, SEP-208*, 1956, Feb. 23, pp. 23). The technique developed in the ceramic industry was applied experimentally to stainless steel. Plaster moulds were used and the metal powder was bonded with alginate, cast centrifugally, and sintered at 1320° C in H_2 for 16 h. Structures and physical properties were determined, and the strength was comparable with wrought stainless steel and with cold-pressed and sintered steel powder.

Fundamentals of Sintering—I. A. Pranatis and L. Seigle. (*U.S. Atomic Energy Commission, Tech. Inf. Extension, SEP-229*, 1956, Oct. 5, pp. 19). Studies on mechanism were made using Cu_2O and the effect of O_2 pressure was measured. This did not agree with the Wagner Theory. Studies with inert markers were also carried out, but the interpretation is not clear, though a general diffusion mechanism was indicated.

FERRITES, CERMETS AND CARBIDES

On the Cause of Pressure Anisotropy in Magnetic Hard Ferrites. H. Stäblein. (*Tech. Mitt. Krupp*, 1957, **15**, Dec., 165–168).

Determination of the Gyromagnetic Ratio and the Magnetic Resonance Damping Coefficient of Ferrites. H. G. Beljers. (*Philips Res. Rep.*, 1958, **13**, Feb., 10–16).

Electrical Properties of $FeTiO_3$-Fe_2O_3 Solid Solution Series. Y. Ishikawa. (*J. Phys. Soc. Japan*, 1958, **13**, Jan., 37–42).

Uniaxial Anisotropy in Iron-Cobalt Ferrites. S. Iida, H. Sekizawa and Y. Aiyama. (*J. Phys. Soc. Japan*, 1958, **13**, Jan., 58–71).

Low Temperature Heat Capacity and Thermodynamic Properties of Zinc Ferrite. E. F. Westrum jun. and D. M. Grimes. (*J. Phys. Chem. Solids*, 1957, **3**, (1/2), 44–49).

The Crystal Structure and Ferrimagnetism of Yttrium-Iron Garnet, $Y_3Fe_2(FeO_4)_3$. S. Geller and M. A. Gilleo. (*J. Phys. Chem. Solids*, 1957, **3**, (1/2), 30–36).

Lattice Changes in Spinel-Type Iron Chromites. M. H. Francombe. (*J. Phys. Chem. Solids*, 1957, **3**, (1/2), 37–43).

Electronic Properties of Transition-Metal Oxides—I. J. D. Dunitz and L. E. Orgel. (*J. Phys. Chem. Solids*, 1957, **3**, (1/2), 20–29).

Predicting the Thermodynamic Stabilities and Oxidation Resistances of Silicide Cermets. A. W. Searcy. (*J. Amer. Ceram. Soc.*, 1957, **40**, Dec., 431–435).

Superalloys and Cermets. J.-A. Ternisien. (*Techn. Mod.*, 1957, **49**, Aug., 444–447). The chemical composition, mechanical properties and physical properties of various cermets and of several Ni and Co alloys are tabulated. The properties and fabrication of cermets, and some of the types available are very briefly described.—B. C. W.

The Present Stage of Development of Heat-resistant Carbide Materials in the East German Republic. F. Thümmler and G. Blum. (*Neue Hütte*, 1957, **2**, Dec., 762–763). The following systems were investigated: TiC-TaC-Co-Ni-Cr, TiC-TaC-Co-Ni, TiC-TaC-Ni, and TiC-Cr_3C_2-Ni. Industrial processes for the production of these alloys were developed, and density, hardness, bending strength, resistance to sudden changes of temperature, and oxydation characteristics were determined.

The Manufacture and Application of Tungsten Carbide in Australia. W. J. Kelsey. (*J. Inst. Prod. Eng.*, 1958, **37**, Feb., 91–104).

PROPERTIES AND TESTS

Steelmen View Standards. (*Steel*, 1958, **142**, Jan. 20, 77–79). This essay describes the difficulties in setting standard specifications in metallurgical practice, and the limitations and uses of standards.—D. L. C. F.

Proposed Recommendations Affecting Standards on Steel. (*Proc. A.S.T.M.*, 1956, **56**, 112–125).

Test Methods for Cast Irons. G. Cois. (*Fond., Ital.*, 1957, **6**, Oct., 407–412). [In Italian]. The paper summarizes the findings of the International Committee on testing methods for cast irons. The various tests

proposed are briefly described and specifications are given.—M. D. J. B.

The Decomposition of Metals Other than those of the Titanium Group by the Hot Filament Technique. R. A. J. Shelton. (*Metallurgia*, 1957, **56**, Dec., 283–289). Iron of high purity is produced by the decomposition of ferric iodide at 900° C. Decomposition of the chloride at temp. < 910° C yielded a single crystal deposit.—A. D. H.

Study of the Quality of Steel Cables Used in Elevators. K. Ehrenberg. (*Bol. A. B. M.*, 1957, **13**, Jul., 267—282). [In Portuguese]. Details of life tests on cables of national, North-American, and European origin are described; the 7-m test tower was designed to simulate service conditions. Mechanical tests and metallographic examination were also employed in this study. Details of the necessary requirements (for ½-in. cables) are given; included in these are: (i) for lifts with V-type pulleys. Seale (regular lay) construction is recommended, (ii) the core should be of hard fibre such as high-grade sisal, never of jute, (iii) external steel strands should be 0·38% C minimum, internal and central strands 0·50% C minimum, both of a sorbitic and free ferrite structure.—P. S.

Technical Surfaces. K. V. Olsen. (*Dansk Tekn. Tidsskr.*, 1958, **82**, Jan., 6–12). A proposal for a Danish standard for roughness of surfaces, which is now before the Council of Standards, is rendered in full. Micro- and macro-geometrical notions, calculation of physical details and signs on working materials are given. There are 13 figures and 8 tables giving explanatory details.

Control Instrument for Checking the Degree of Finish of Plane Surfaces. M. Joannis. (*Microtecnic*, 1957, **11**, (5), 211–215). An optical method in which the scatter pattern of an incident beam is observed is described. These traces are compared with micrographs of the surface.

On the Trial Production of a Photoelasto-Plasticity Camera for Use in Photoplastic Analysis of Real Metal Structures. S. Suzuki and K. Kawata. (*Reports Scientific Research Institute, Tokyo*, 1957, **33**, July, 171–176). **On a Birefringent Coating to Analyse the Plastic Behaviour of Real Metal Structures.** K. Kawata and S. Suzuki. (185–198). [In Japanese].

Direct Observation of Dislocations and Their Movement in Metal Foils. P. B. Hirsch, R. W. Horne and M. J. Whelan. (*Proc. Stockholm Conf. on Electron Microscopy*, 1956, Sept., 312–315). Micrographs of dislocations are shown and the mode of image formation is described. The studies were carried out on Al foil.

The Electronic Structure of the Metals of the First Transition Period. W. M. Lomer and W. Marshall. (*Phil. Mag.*, 1958, **3**, Feb., 185–203).

Studies on Interfacial Effects between Mercury and Steel. J. J. Droher. (*U.S. Atomic Energy Commission Tech. Inf. Service, ORO-60*, 1952, June, pp. 92). A literature survey (89 references), and experiments on heat transfer are reported. Interfacial electrical resistance was measured with apparatus described and tests under wetting and non-wetting conditions were carried out on low-C and stainless steels and on Cu. Various factors influencing wetting (as newly-drilled surfaces and Na addition) are noted.

Determination of the Critical Range of Brittleness for Smooth Tensile Test-Pieces. I. E. Kontorovich and B. M. Voshedchenko. (*Zavods. Lab.*, 1957, **23**, (11), 1362–1365. [In Russian]. In the method described the starting temperature of the critical brittleness range for static tension is determined from the appearance of the fracture of high-tempered smooth test pieces of structural steel. The influence of heat treatment conditions on the type of fracture obtained at temperatures down to −200° C was studied for types 12Kh2N4A, 12Kh2N3MA, 18KhNVA and 23Kh2NVFA steels. Formation of fractures with breakdown along meridional planes corresponded to the start of the critical brittleness range; transverse fractures in the transition zone of the neck indicate a test temperature below that of the upper limit of the cold-brittleness range.

Piecemeal Yielding of Mild Steel. K. Farnell. (*Engineering*, 1958, **185**, Jan. 17, 92–93). Overstrained mild steel specimens were examined and hardness measurements were made on partially-yielded tensile specimens. The slip bands were found to be invariably fully yielded and the material between the bands to be still in an elastic state so that there is no intermediate state in the individual elements. Curves are shown and the mechanism is formulated. Studies of compression yield, reversed load conditions and effects of ageing up to 2 years are also referred to. Elastic recovery is far from complete and the partial recovery can be allowed for by a small modification of the basic reversal characteristic.

Yield Point and High-Temperature Proof Stress of Carbon-Manganese Steel. J. Glen. (*J. West Scotland I.S.I.*, 1958, *Paper*, 505, pp. 40). Proof stresses at temperatures up to 450° C for steels with tensile strengths between 24 and 35 tons/in.² at ordinary temperature have been measured. The steels were examined as-rolled and also after tempering or normalizing. Results are summarized. The extent to which the factor of safety can be based on U.T.S. was studied below creep range.

The Mechanical Properties of Type 201 Chromium-Nickel-Manganese Stainless Steel Sheet. R. A. Walsh, R. L. Cook and R. A. Lula. (*Proc. A.S.T.M.*, 1956, **56**, 923–944). Tensile and compressive properties of 2 commercial heats of sheet with cold reductions 0–60% were measured. Tensile tests were made parallel and perpendicular to rolling direction and the effects of stress-relieving treatments at 600°, 800° and 900° F were determined for both.

Further Considerations on the Ductility of Iron at 4·2° K. R. L. Smith and J. L. Rutherford. (*Acta Met.*, 1957, **5**, Dec., 761–762). **Ductility of Iron at 4·2° K.** Z. S. Basinski. (736–764). A. W. Sleeswijk. (764–765). A series of letters. Alleged correlation of serrations in the curve with visible constrictions in the specimen and the effects of grain size are discussed.

Note on the Possible Modes of Slip in Body-Centred Tetragonal Crystals of Martensite. M. Doi. (*Bol. Assoc. Brasil Met.*, 1957, **13**, Apr., 139–145). [In Portuguese]. Recent work on martensitic transformations is discussed. A change in the mode of slip of such structures analogous to that occurring in indium, i.e. {101}, [101] is suggested. In accordance with the Mallard law {101} planes probably have the pseudo-symmetry necessary to become slip planes. Observed deviations in slip of the {112}, [111] type may be caused by the tetragonality. It is suggested that with an axial ratio of about 1, slip of the {101}, [101] type cannot occur but that it might when the ratio approaches that of indium (1·078)—approximately that of a 1·7% carbon steel.—P. S.

Strength and Plasticity of Modified Cast Iron in Varying Stressed States. Yu. I. Yagn and V. V. Evstratov. (*Doklady Akad. Nauk S.S.S.R.*, 1957, **113**, (3), 573–575). Samples of modified cast iron were subjected to linear stretching and non-linear biaxial and triaxial compression. The aim was the determination of stresses and strains at the stage of collapse, but with some samples this stage was not reached.—S. I. T.

High-Temperature Plasticity Measurements in Controllable Atmospheres. J. D. Mackenzie. (*J. Sci. Inst.*, 1957, **34**, June, 246–247). Apparatus for the investigation of wüstite, magnetite, and haematite is described for use up to 1200° C.

The Effect of Rate of Deformation on the Position and Formation of Yield-Point in Steel. F. X. Eder and H. J. Wiesotski. (*Z. Metallk.*, 1957, **48**, Oct., 561–564). Iron with 0·05% C was examined. The Becker-Orowan equation holds at medium and high rates of strain but not at low rates. Cottrell's model of dislocations can be used.

The Flow and Fracture of Nodular Cast Iron. W. R. Clough and M. E. Shank. (*Trans. A.S.M.E.*, 1957, **79**, Nov., 1911–1920). The modulus of elasticity and Poisson's ratio of pearlitic spheroidal graphite iron were found to be constant, and it was found to yield in accordance with distortion-energy theory, allowing for stress concentration at the graphite nodules. There is a density change on plastic deformation due to separation of matrix from graphite. Brittle cleavage facets are revealed by fractography. Cleavage fracture is not obtained in tension but may be obtained in presence of notches or at low temperatures.

On the Forces Acting on the Foundation of an Hydraulic, Vertical Tensile-Testing Machine during Fracture of the Test-Piece, with Particular Reference to Elasticity in the Base. O. Schwaninger. (*Schweiz. Arch. Wiss. Techn.*, 1957, **23**, April, 105–114; May, 156–163). The reaction forces occurring at fracture of a tensile-test piece are discussed and calculated. Unpleasant vibrations of the foundation and surroundings are avoided by using elastic foundations. The author shows how the dynamic forces acting on the baseplate during fracture can be calculated and the results used for construction of suitable vibrating baseplates for this type of apparatus. Unpleasant side-effects are thus eliminated. Results can be applied to vertical as well as to horizontal tensile testing apparatus.—B. P.

Notch-Tensile Test and its Application in Assessing the Danger of Brittle Fracture. Part I. H. Flössner and K. Matthaes. (*Schweiz. Arch. Wiss. Techn.*, 1957, **23**, Aug., 249–258). The authors discuss the conditions necessary for arriving at correct results. Four types of fracture are discussed. The influence of temperature, composition, and velocity is considered. (38 references).—B. P.

The Tensile Properties of Pearlitic Nodular Irons in Air and Water. G. N. J. Gilbert. (*Brit. C.I. Res. Assoc. J. Res. Dev.*, 1957, **6**, June, 630–637). The tensile strength of these irons is decreased in water or aqueous solutions and also in mercury. The decrease is usually greater in normalized than in as-cast irons. The strength was found to be unaffected in a number of organic liquids.—B. G. B.

Some Properties of Stresscoat Under Dynamic Loading. A. J. Durelli and J. W. Dally. (*Proc. Soc. Exper. Stress Anal.*, 1957, **15**, (1), 43–56). The method of brittle coating stress analysis is limited by the need for dynamic calibration and by the difficulty of locating the last crack. A study was made on the effect of coating number, coating thickness, and curing temperature on the dynamic and static strain sensitivities of Stresscoat. The dynamic is usually greater but there are particular conditions where they are nearly the same. The Statiflux penetrant method of crack detection was superior to visual and dye etchant methods.

The High Temperature Tensile Properties of Nodular Graphite Cast Irons. K. B. Palmer. (*Brit. C.I. Res. Assoc. J. Res. Dev.*, 1957, **6**, June, 638–659). The tensile properties of two pearlitic and two ferritic industrially produced nodular irons are given for temperatures up to 600° C. Pearlitic irons are shown to have markedly different properties in the range 450–600° C. As was found to improve the tensile strength and elongation of pearlitic nodular irons at high temperatures. P was shown to have a similar effect to that of As. As promotes the formation of spheroidal graphite nodules.—B. G. B.

The Effect of Rate of Deformation on the Forces During Tensile Tests. J. Wantuchowski. (*Arch. Hutn.*, 1957, **2**, (1), 47–92). Tensile tests are classified and criteria advanced. An expression is derived for true tension and degree of work hardening and it is modified to express the static tensile test, creep under various conditions, and relaxation. Tests were then carried out to bring the effect of rate of deformation into Krupkowski's formula, the tests ranging from 8 sec to 18 days and the results were formulated. An example is worked out, and comparisons for copper wires were made, also for silver and monel metal. The relation to melting point is finally discussed.

Static Properties of High Strength Steel. E. P. Klier, B. B. Muvdi, and G. Sachs. (*Prod. Eng.*, 1957, **28**, Mid-Oct., B24–B27). 4340 steel (4 heats) and 6 other steels were tested for hardenability, tension properties, notch-strength variations and notch-strength with eccentric loads. Effects of heat treatments are shown. All data is represented graphically.

The Case Against the Torsion Test. J. B. Caine. (*Foundry*, 1957, **85**, Nov., 86–92). It is claimed that tensile tests undervalue castings and overvalue wrought metals with a discussion of brittle fracture. The interpretation of notch impact testing is questioned. Ductile-to-brittle transition temperatures are given and comparison with fatigue is made. Advantages of cast metals are pointed out, also the value of non-destructive tests.

Investigation of the Degree of Heat Treatment of Tool Steels in Tension and Compression. Z. M. Konyushko. (*Vestnik Mashin.*, 1955, (2), 67–69, 73). The article sets out the results of exhaustive investigations on various marks of steel under tension and compression. The tensiometer was graduated in 0·002 mm.

X-Ray Investigation of Effects Accompanying Prolonged Extension of Steel at High Temperatures. M. Ya. Fuks, N. V. Slonovskii, and L. I. Lupilov. (*Izvest. Akad. Nauk, Seriya Fiz.*, 1956, **20**, (6), 671–675). [In Russian]. The aim of this investigation was to elucidate what X-ray signs accompany the weakening of steel when the duration of applied stress is increased and the stress is above the yield point. The main part of the investigation was on forged type 35KhNM steel, with supplementary experiments on type St. 20. Special flat test pieces and mean relative elongation rates of 4–0·005%/min were used. X-ray pictures were taken without rotation in a cylindrical camera with iron radiation and also on a flat film with back reflection of chromium and cobalt radiation.—G. K.

Plastic Deformation of Steel in the Tensile and Hardness Tests. W. Truszkowski. (*Arch. Hutn.*, 1955, **3**, (3), 345–377). Formulæ derived for metals showing a flat portion on the stress–strain curve where deformation takes place at constant stress and shown to apply to the results of tests on five annealed steels and agreement between calculated and measured hardnesses was satisfactory. For comparison an austenitic steel showing no sharp yield point was tested. (32 references).

Some Remarks on Drawability Tests on Steel Sheet Carried out on the Press. B. Otto and J. Teindl. (*Sborník Vědeckých Prací Vysoké Školy Báňské v Ostravě*, 1957, **3**, (1), 35–45). [In Czech]. It is shown that in cold pressing the total reduction is more important than the number of draws in relation to drawability. The latter is determined in the last analysis by impurities in the steel, and even slow drawing and the use of several passes cannot substantially increase the inherent drawability. The suitability of cupping tests carried out directly on presses for purposes of assessing drawability is discussed, and examples taken from practice are considered.—P. P.

Influence of Repeated Bending Loads on Biaxial Residual Stresses in Shot-Peened Plates. T. M. Elsesser. (*Trans. A.S.M.E.*, 1957, **79**, Nov., 1904–1910). Residual stresses were measured in the region of the peened surface and were found to "fade" at least to half their original values in 10200 load cycles in SAE 4340 steel.

The Effect of Crystal Orientation on the Formation of Slip Markings on the Surface of Mono-Crystal α-Iron Samples Subjected to Alternating Bending Stress. M. Hempel, A. Kochendörfer, and E. Hillnhagen. (*Arch. Eisenhütten.*, 1957, **28**, Aug., 433–444). A report is given of experiments with single crystals of α-iron having about 0·006% C produced by the recrystallization method. The samples were polished by mechanical means and orientation was determined by means of Laue reflection diagrams. It was shown that the mechanism of slip under alternating stress is fundamentally similar to that under tensile stress.—L. J. L.

On the Nature of the Scale Effect in the Breakdown of Metals. E. M. Shevandin, I. A. Razov, R. E. Reshetnikova, and B. N. Serpininov. (*Doklady Akad. Nauk S.S.S.R.*, 1957, **113**, (5), 1057–1060). Steel samples of various sizes were subjected to bending deformation and the relation between the size of sample and its breakdown was studied.

Special Techniques for Increasing Strength and Fatigue Life of Steel Stressed in Torsion. N. E. Hendrickson. (*A.S.T.M. Bull.*, 1957, Sept., 40–42). Shot-peening and presetting of torsion bar springs is described, and the effect on fatigue life is assessed.

On the Determination of the Plasticity Limit during Torsion. M. P. Markovets. (*Zavodskaya Laboratoriya*, 1957, **23**, (6), 715–720). [In Russian]. A new way of estimating deformation of the surface layers is proposed. The calculation of the deformation limit formula gives a good approximation in comparison with the values obtained by fracture. The magnitude of this limiting plasticity of deformation also depends on the length of the specimens.—L. H.

The Deformation Characteristics of C45 Steel in Compression and Shearing as a Function of Temperature and Rate of Deformation. W. Lueg and H.-G. Müller. (*Arch. Eisenhütten.*, 1957, **28**, Aug., 505–516). The deformation strength and shear strength of an unalloyed steel with 0·46% C has been studied as a function of deformation and deformation rate at temperatures ranging from 700° to 1100° C.

Nonhomogeneous Yielding of Steel Cylinders. 1—Mild Steel. M. C. Steele and L. C. Eichberger. (*Trans. ASME*, 1957, **79**, Oct., 1608–1618). Formation and propagation of Lueders' lines is described, strains are recorded, and comparison is made with the theories of Thomas and Koiter, agreement with the latter being the better.

Mechanical Properties Versus Microstructure. J. B. Malerich and G. V. Cash. (*Metal Progress*, 1957, **72**, Aug., 106–111). Tempered martensite is considered to be the best microstructure for low alloy Cr–Mo–V steel if impact strength and ductility is desired. Fine bainite is considered best if short time tensile and stress-rupture strength is desired. Coarse bainite has the best creep strength at 900 and 1000° F.—B. G. B.

Impact Properties of Slack-Quenched Alloy Steels. M. R. Meyerson and S. J. Rosenberg. (*J. Res. N.B.S.*, 1957, **59**, Oct., 273–288). An extensive investigation is reported of specimens prepared by a slack quenching process controlled to produce uniform and controlled hardnesses and microstructures throughout the cross section. Steels of 81XX type with or without B were used. The process is detrimental to impact resistance and factors are identified. Two steels quenched to the same hardness showed impact properties increasing with alloying and decreasing with C; both were improved by tempering and the differences between them were reduced.

The Use of the Photometric Method for the Investigation of Fractures in Steels. Z. N. Krasil'shchikov and E. N. Shvach. (*Zavod. Lab.*, 1957, **23**, (8), 959–961). [In Russian]. The photometric method of investigation allows the calculation of the relative brittleness of the crystal faces and of the viscosity of fibrous fractures. In conjunction with fractography it can be used successfully for the investigation of brittle and viscous fractures.—L. H.

Method of Investigation of Fatigue of Steels under Impact. H. F. Vyaznikov and S. S. Ermakov. (*Zavod. Lab.*, 1957, **23**, (9), 1095–1097). [In Russian]. A special machine for this investigation is described as well as the results of experiments conducted in liquid media and in the atmosphere. The results agree very well with those observed with drills working in wet media, under cyclic impact.—L. H.

Impact Properties of High-purity Nickel–Chromium–Molybdenum Alloys. J. M. Capus and G. Mayer. (*J.I.S.I.*, 1958, **189**, July, 255). [This issue].

Test Reduces Overdesign Problem. (*Steel*, 1957, **141**, Oct. 7, 184–192). A test developed by the National Bureau of Standards to measure the impact properties of slack quenched steels is described; this measurement gives useful design-data. A Charpy impact specimen is end-quenched by immersion under conditions determined by the microstructure it is required to test; the specimen is then prepared, surveyed, notched, and tested.

Softening of Steels by Cold-Working. P. Chollet and H. P. Tardif. (*Nature*, 1957, **180**, Oct. 12, 754–755). Three steels were tested, Type 420 stainless does not show the effect but AISI-4340 and Hy-Tuf do. Tensile specimens were scribed with lines 2 mm apart and strained and Vickers hardnesses determined. The internal strain effect does not seem to be the only factor and a precipitation process is possibly occurring.

On an Early Period of Stress Relaxation in Metals. V. Z. Tseitlin. (*Zavodskaya Laboratoriya*, 1957, **23**, (7), 846–849). [In Russian]. A rapid fall in stress immediately after application of an instantaneous load is due in the main to the slipping of the grains up to their boundaries. The experiments conducted on various steels and at varying temperatures allow of some practical conclusions towards increasing resistance to stress relaxation, viz.: to reduce the length of the boundaries of the grains by increasing their dimensions mainly by way of heat treatment, to increase heat resistance of the intergranular layers, and through appropriate heat treatment to obtain a structure with a smaller number of grains of different phases, with rounded geometrical regular patterns.—L. H.

Study of Modifications in Structure Occurring During Hot Deformation of Stable Austenite and Soft Iron. R. Tamhankar, G. Pomey, J. Plateau, and G. Henry. (*Compt. Rend.*, 1957, **245**, Sept. 30, 1132–1135). Steel with 36% of Ni and 10% Cr and iron with 0·003% C were examined during tensile testing at high temperatures and in creep. Slip planes, polygonization, and boundary migration were observed and related and the possibility of determining the equicohesion temperature is discussed.

Determination of Heats of Activation Involved in the Hot Deformation of Stable Austenite and of Soft Iron. R. Tamhankar, C. Boulanger, A. Constant, J. Plateau, C. Rossard, and C. Crussard. (*Compt. Rend.*, 1957, **245**, Oct. 7, 1242–1244). Austenitic steel with 36% Ni and 10% Cr and iron with 0·003% C were tested in creep at 550–800° C, in torsion at 1000–1200° C and for internal friction up to m.p. and heats of activation calculated. The respective values found were ~ 68,000 and ~ 65,000 cal/mole.

Solubility and Diffusion of Carbon in a Silicon–Iron Alloy. D. A. Leak and G. M. Leak. (*J.I.S.I.*, 1958, **189**, July, 256–262). [This issue].

New Researches on Heat-Resisting Vanadium Steels. A. Roos. (*Mét. Constr. Mécan.*, 1958, **90**, Jan., 9, 11–13). Compositions, heat-treatments, creep tests and a study of refractoriness and their dependence upon V content are shown. Also structures are illustrated, and the findings are correlated with solution of carbides.

METALLOGRAPHY

Recent European Advances in Optical Metallography. R. Mitsche. (*Met. Prog.*, 1958, **73**, Jan., 97–101). An illustrated description of modern microscopical equipment for metallography used in Europe is presented. Hot stages, electrolytic polishing, and electron microscopy are briefly considered.—B. G. B.

Clue to Stronger Steel. (*Steel*, 1957, **141**, Nov. 25, 98). A note on a research project at General Electric Research Laboratory, N.Y., is given. The use of the electron microscope on metal surfaces enables strength to be assessed. Examination of extremely small microstructure details is necessary in developing modern materials.—D. L. C. P.

Direct Observation of Metallic Surfaces by Reflexion [In Electron Microscopy]. C. Fert. (*Proc. Stockholm Conf. on Electron Microscopy*, 1956, Sept., 8–12). [In French]. The arrangement used is described and the electron optics formulated. The micrographs obtained are shown.

A Method for Making Positive Replicas and the Preparation of Steel Specimens for Electron Microscopy. J. B. Le Poole and F. van Wijk. (*Proc. A.S.T.M.*, 1956, **56**, 409–414). Negative Ag and positive C replicas are made and tungsten oxide shadowing is carried out. The results are illustrated.

Development of the Structure of Welds in 18-8 and 25-20 Chrome-Nickel Steels by Electropolishing and Electroetching. A. A. Rossoshinskii. (*Avtom. Svarka*, 1953, **6**, (6), 52–55). Treatment for 3–6 mins. of a polished surface in one of 6 electrolyte solutions recommended for various purposes (revealing grain boundaries, carbides or σ-phase or staining α-iron, etc.) gives surfaces suitable for examination.

Electropolishing of Ferrous Metal Specimens for Electron Metallography. F. W. Boswell. (*Proc. A.S.T.M.*, 1956, **56**, 426–435). A chromic-acetic acid method is described and the results are illustrated.

Chemical Polishing of Steel for Electron Metallography. R. L. Scott. (*Proc. A.S.T.M.*, 1956, **56**, 444–457). An oxalic acid-hydrogen peroxide bath was used. Mechanically polished specimens were also prepared for comparison.

Determination of Carbides in Stainless Steel by the Electrolysis Method. M. M. Shapiro. (*Zavods. Lab.*, 1957, **23**, (11), 1292–1294). [In Russian]. Results obtained in the determination of carbides in stainless steels by a method developed by the Central Research Institute of Ferrous Metallurgy are compared with those obtained by the Saverina method. Analysis of carbides from stainless steel after various heat treatments are given.

Metallographic Studies of Iron Carbide and Tungsten Carbide. F. J. Radd and L. C. Crowder. (*Nature*, 1958, **181**, Jan. 25, 258–259). A letter. Cracking and twinning have been observed in carburized iron and steel and in massive Fe-Mn carbide without mechanical working. Etching methods are given. The twins are regarded as an index to carbide orientation and morphology and they, and the cracking, as signs of high internal stresses.

Autoradiography Traces Additives in Metals. R. H. Herrmann. (*Foundry*, 1958, **86**, Jan., 121, 124). A brief description is given of the use of a radioactive tracer technique to study the distribution of Ce in a nodular iron, and of the use of neutron activation analysis to examine the distribution of B in steel.

A Study of the Distortion of High-carbon High-chromium Die Steels. K. Sachs. (*J.I.S.I.*, 1958, **189**, July, 216–224). [This issue].

Crystalline Structure and Recrystallization of Metals. W. G. Burgers and T. J. Tiedema. (*Metalen*, 1957, **12**, Nov. 30, 458–464; Dec. 31, 502–508). [In Dutch]. The modern conception of grain boundaries is described and it is shown that the formation of the latter depends on the mutual orientation relationship of the contiguous grains. The paper goes on to show why large grains grow at the expense of smaller ones, also why a metal crystal contains inclusions. To conclude, the formation of recrystallization nuclei is discussed. The text includes numerous graphs and microphotos. (34 references).—F. R. H.

Nondestructive Determination of Grain Size in Metals. N. Grossman. (*U.S. Atomic Energy Commission, Tech. Inf. Service*, 1955, Aug., *SEP*-184, pp. 31). Ultrasonic measurements are described on steel, brass and Zr. A back-reflection method was used to measure pearlite distribution in low-carbon steels.

Migrations of Grain Boundaries Studied with the Emission Election Microscope. R. Arnal and M. Sorel. (*Proc. Stockholm Conf. on Electron Microscopy*, 1956, Sept., 318–319). Examination by time-lapse cinephotography is described. Effects in Ti (which was found to give the most rapid results) are described at 1000°.

On the Mechanism of Formation of Spheroidal Graphite in Magnesium-Inoculated Cast Iron. V. P. Pavlov. (*Izvest. Akad. Nauk. Otdel. Tekn.*, 1957, (4), 33–39). [In Russian]. After reviewing existing views on the mechanism of formation of spheroidal graphite in Mg-inoculated iron and on the basis of known phenomena accompanying the process, the author proposes the following mechanism. Mg reacts with carbon forming MgC_2 which dissociates to Mg_2C_3 and free carbon, on further heating (up to 1200° C) Mg_2C_3 decomposes into 2Mg and 3C. C particles stirred in the iron are pelletized in the moving medium forming globular graphite nuclei.—V. G.

New Oxidizing Method for Revealing Austenitic Grain. Y. Imai and H. Hirotani. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1957, **9A**, Dec., 467–475). Specimens are heated in vacuo, a little air is admitted (3–5 sec.) and the specimens are dropped into molten borax to remove the oxide film and quenched in water.

On Austenite Grain Control in Killed Low-Carbon Steels. T. Tanoue. (*Sumi. Met.*, 1957, **9**, July, 139–142). [In Japanese]. Coarse grained steels for boiler tubes have higher creep strength. The effect of Al on grain size was examined. It appears to be necessary to limit dissolved Al to ~ 0·004%, and, to prevent blow hole formation, to keep Si over 0·2%.

Electron Microstructure of Some Quenched-and-Tempered, Low-Alloy, Medium-Carbon Steels. R. P. Sernka and S. T. Ross. (*Proc. A.S.T.M.*, 1956, **56**, 398–408). Micrographs of tempered SAE 4063, 4140, and 5150 steels are shown and heat treatments tabulated.

Criterion for Peritectic and Eutectic Reactions. M. Hillert. (*J.I.S.I.*, 1958, **189**, July, 224–226). [This issue].

Solidification of Hypereutectic Magnesium-Treated Cast Iron. A. V. Chernovol. (*Metallov. Obra. Met.*, 1957, (10), 21–22). Graphite formation was studied in 4·73% C iron treated with Mg and Fe-Si and appeared to indicate that the graphite is not formed from cementite but directly from solution.

Comparison of Surface and Volume Transformations in Alloy Steel. L. S. Birks and R. T. Seal. (*Proc. A.S.T.M.*, 1956, **56**, 436–443). A Ni-Cr steel and AISI 4140 were used. Micrographs are shown. In both surface and volume bainite was indistinguishable and whether formed in cooling or isothermally it appeared the same as long as transformations in the same temperature region were compared. Some difference in surface and volume martensite was observed.

Observations of Bainite Formation with the Thermionic Emission Microscope. I. I. Bessen. (*Proc. A.S.T.M.*, 1956, **56**, 415–425). The transformations at 950° F, 800° F, 1025° F and carbide formations are shown. Lattice strain in austenite is necessary for bainite formation and the driving force has two components, this strain and the chemical or solubility effect. Both depend on temperature. It remains undetermined whether supersaturated ferrite is formed or whether ferrite and carbide precipitate together.

Pearlite and Bainite Structures in Three Carbon Steels with 0·18%, 0·50% and 0·86% C. S. Modin. (*Proc. Stockholm Conf. on Electron Microscopy*, 1956, Sept., 319–321). [In German]. Isolation of constituents and structures seen are described.

The Mechanism of the Action of Aluminium upon Secondary Austenite Grain in Steel. D. S. Kamenetskaya and I. B. Piletskaya. (*Problems of Metallography and Metal Physics, 4th Coll. Papers* 1955: Moscow, 103–112). An investigation is reported leading to the conclusions that Al facilitates nucleation of secondary austenite during heating and retards growth rate. It appears to reduce surface energy and to increase activation energy. It is suggested that Al inhibits diffusion of carbon.

Evidence for a Regeneration Phenomenon in a Single Crystal of α-Iron by Conservation of Nuclei During the $\alpha = \gamma$ Allotropic Transformation. G. Donzé and R. Faivre. (*Compt. Rend.*, 1957, **245**, Dec. 16, 2277–2280). It is shown that a crystal containing impurities such as C or N when heated a little above its transformation point is regenerated on cooling. An explanation is offered based on the retention of α-iron nuclei in the polycrystalline γ-structure.

On Some Relationships in the Kinetics of Martensite Transformations. G. V. Kurdyumov and O. P. Maksimova. (*Izvest. Akad. Nauk, Otdel. Tekn.*, 1957, (6), 4–11. [In Russian]. On the basis of the literature data (38 ref.) the authors concluded that the existence of the temperature dependence of the kinetics of the austenite-martensite transformation, which is characteristic for all phase transformations, is a well-established fact. Thermal vibration of atoms in the crystal lattice is one of the main factors determining the kinetics of martensite transformations. A "thermal" transformation in fact results in thermal formation of nuclei which takes place under certain conditions (a small work of formation of nuclei on high supercooling, large energy of thermal vibrations at insufficiently low temperatures) with a very high velocity. The presence of "prepared" places for the formation of nuclei leads only to an increase in temperature at which the nuclei are formed in those places under the influence of thermal fluctuations.—V. G.

On the Occurrence of ε-Carbide in Iron. F. W. C. Boswell. (*Acta Cryst.*, 1958, **11**, Jan. 10, 51–52). Electron-diffraction studies support the conclusions of Tsou that ε-carbide occurs in low-carbon irons quenched from 720° and aged at 200° C for 2 h or at 400° C for 1 h. Alternative explanations of the pattern obtained are considered.

The Transformation Characteristics of Steels with 12–14% Cr. W. Peter and W. Matz. (*Arch. Eisenhüt*, 1957, **28**, Dec., 807–823). Metallographic and dilatometric studies on steels with 0·07–2·07% C and 12–14% Cr are reported. Magnetic saturation and hardness were also studied. Diagrams are given to show the transformation characteristics of steels with 12–14% Cr with emphasis on the effects of austenitisation temperature and carbon content.—L. J. L.

Conditions for Stability of Graphite, Iron, and Its Oxides and Carbides. D. I. Cameron. (*J.I.S.I.*, 1958, **189**, July, 251–255). [This issue.]

An Investigation of the Fine Structure of Chromium-Iron Annealed after Hardening by High Speed Heating. I. N. Kidin. (*Izvest. Akad. Nauk. Otdel. Tekn.*, 1957, (4), 63–69). [In Russian]. An investigation of the fine structure on annealing of Cr–Fe, containing 5·2% Cr, after hardening by slow heating or by high-frequency heating with high heating rates 50 and 1000° C°/sec was carried out. It was found that: (1) The degree of fineness of coherent zones and an increase in stresses of the second order on hardening is determined by at least three factors: phase work-hardening, caused by volume changes during the $\gamma \rightarrow \alpha$ transformation, the intensity of these volume changes which depend on the rate of cooling during hardening; and the nature of the fine structure of the γ-phase, which is determined by an interrelated influence of the temperature and rate of heating. The comparison of the influence of the fine structure of austenite and the intensity of $\gamma \rightarrow \alpha$ transformations indicates that the effect of the second of the above factors is considerably smaller. (2) The more metastable is the structure formed after hardening (i.e., the smaller are the dimensions of coherent zones and the larger are stresses of the second order), the lower is the annealing temperature at which a noticeable growth of coherent zones and a decrease in the second-order stresses takes place. This temperature is 200–150° C below the temperature at which the growth of coherent zones begins. (3) The temperature at which the hardness begins to decrease corresponds to the temperature at which the growth of coherent zones takes place. A large temperature difference between the beginning of a decrease of second-order stresses and the beginning of the growth of mosaic blocks suggests the possibility of establishing annealing practices at which a considerable decrease of second-order stresses can take place with preservation of the high strength of the alloy.—V. G.

Phase Transformations in Chromium-Molybdenum-Iron Alloys Rich in Chromium. N. V. Ageev, L. N. Guseva and K. P. Marko-

vich. (*Izvest. Akad. Nauk, Otdel. Tekn.*, 1957, (4), 23–32). [In Russian]. Studies of the kinetics of phase transformations in alloys based on Cr, containing Mo and Fe in amounts of from 15 to 25%, and the influence of some alloying elements (C, Ti, Al and Si) on these transformations are described.—V. G.

X-Ray Study of Carbide Phase of Patented Steel Wire. V. M. Golubkov and V. K. Kritskaya. (*Problems of Metallography and Metal Physics, 4th Collection. State Sci. and Tech. Publishers for Ferrous and Non-Ferrous Literature, Moscow*, 1955, 461—464). A 0·8% C steel wire was examined after 25%, 65%, 75% and 95% reduction and after heat-treatment at 400°, 600° and 680° C, the carbides being isolated electrolytically and examined by Fe radiation through a Mn filter. Block sizes observed are tabulated.

Formation of Sigma-Phase in High-Alloy Austenitic Steels and Alloys. E. M. Pivnik. (*Fiz. Met.*, 1956, **2**, (3) 531–537). X-Ray and metallographic studies on 17–20% Cr and 8–20% Ni alloy with 1–2% of Mo, W, Nb and Ti, which were forged into rods of 40 mm dia and quenched from 1150–1200° C, are reported. The formation of intermediate carbides was established, the δ phase of which are nuclei for the σ phase and the more δ formed the smaller are the σ particles. Sigma phase lowers impact value and ductility to an extent depending upon size, shape and distribution.

The Structure of Beryllised Steel. M. L. Bernshtein and V. B. Kishinevskii. (*Izvest. Akad. Nauk, Otdel. Tekn.*, 1957, (2), 144–145). [In Russian]. Results of an investigation of the structure of the diffusion-beryllized layer using coloured ultra-violet microscopy together with spectral and X-ray analysis and measurements of microhardness are described.—V. G.

The Constitution of Alloys of Iron with Ruthenium, Rhodium, Palladium, and Silver. W. S. Gibson and W. Hume-Rothery. (*J.I.S.I.*, 1958, **189**, July, 243–250). [This issue].

CORROSION

Corrosion and Corrosion Research. P. J. Gellings. (*Lastechn.*, 1958, **24**, Jan., 1–5). [In Dutch]. A short description of the fundamentals of the theory of corrosion processes coupled with several illustrated practical examples covering those due to moisture and galvanic action. Some methods of corrosion research are examined and, to conclude, attention is directed to corrosion problems specially arising in welded constructions. Several microphotos appear in the text showing the effects of pitting and intercrystalline corrosion.—F. B. H.

Electroreduction Processes on Oxydized Steel. II. The Electroreduction of Oxygen. A. S. Afanas'ev and E. N. Chankova. (*Zhur. Fiz. Khim.*, 1956, **30**, (10), 2294–2300). Steel with or without an oxidized film is shown to be an effective cathode for O_2 in aqueous alkali solutions. In the absence of, or in presence of weak polarization by external current the potential is determined by the formation of H_2O_2 by the process $O_2 + H_2O + 2e = OH^- + HO_2^-$ and the value of the no-current potential is near this equilibrium value. At higher polarizations the determining process is the reduction potential of H_2O_2. Constants have been determined for various types of steel. **III. The Electroreduction of Iron Oxides.** ((11), 2525–2532). The reduction potential of tervalent iron in the oxide phase of steel immersed in 1·5N KOH has been examined. Mill scale, scale formed at 450°, the layer formed in hot alkaline $NaNO_2$ and rust were present. Steps were observed in the polarization curves, potential-time at a given c.d. and potential-log c.d. curves at −0·82 to −0·94 V varying for the type of oxide examined. The constants for the overvoltage equation were obtained and the effect of aeration on the potentials was observed.

Experimental Contribution to the Phenomena of Cathodic Reduction of Oxygen and Hydrogen Peroxide. G. Bianchi. (*Corros et. Anticorros.*, 1957, **5**, May, 146–152). A fundamental study is reported in view of the importance of the processes in corrosion phenomena.

Non-Chemical Factors Affecting Inhibitor Selection and Performance in Air-Conditioning Cooling Waters. S. Sussman. (*Corrosion*, 1957, 1957, **13**, Nov., 701–710). Recirculating water in cooling systems frequently is or becomes corrosive. Economic, mechanical, human and legal factors often largely militate against the effectiveness of corrosion control programmes. Many practical examples of the difficulties encountered are described. Design faults especially due to modifications after installation often lead to wasted water and loss of inhibitor. Inadequate maintenance may be due to difficulties of access or to use of untrained personnel.—J. F. S.

Corrosion and Adsorption Studies using Sulfonate Inhibitors. A. H. Roebuck, P. L. Gant, O. L. Riggs and J. D. Sudbury. (*Corrosion*, 1957, **13**, Nov., 733–738). Radiometric adsorption and desorption studies are described on sodium and amine salts of sulphonic acids derived from dodecylbenzene oil fractions. Corrosion inhibition properties of these salts are deduced from laboratory tests in H_2S-CO_2-brine-kerosine environments. The effects of concentration, solubility, molecular weight and extent of neutralization of the sulphonic acids on inhibition are described and it is postulated that they function by preferentially occluding oil on to the surface.—J. F. S.

New Methods of Protection against Corrosion and Removal of Rust. (*Zastita Mat.*, 1955, **3**, Feb., 58–61). The author gives an indication of the enormous extent of losses due to corrosion, and outlines the latest methods of removing rust from iron and steel, and preparation of surfaces for the application of protective paints and coatings, mentioning some of the latest products of paint technology, and the use of zinc chromate and zinc tetroxychromate.—M. deO. T.

Protective Anodes for Ships. Recorder. (*Met. Ind.*, 1958, **92**, Feb. 28, 170, 176). A review of published work.

Materials for Corrosion Control. F. W. Fink. (*Ind. Eng. Chem.*, 1958, **50**, Jan., 129A–131A). The use of Ti and Zr sheet, clad metals, inhibitors, additives and cathodic protection and, problems of atomic energy and of corrosion by H_2S are briefly considered, with a note on the corrosion of austenitic stainless steels.

Cathodic Protection of Ships in Transit. H. Arup. (*Dansk Tekn. Tids.*, 1957, **81**, Dec., 265–268). A concise outline of cathodic methods of protecting vessels, both in transit and while laid up, the emphasis being on the former. Commencing with anodes which set up their own potential, first used by Sir William Davy in 1824 and now used in the U.S.A. for the protection of vessels on the slips, the author mentions various anode materials used. Complete protection can be afforded to ships by this method alone, but still better results are obtained where the paintwork is initially in good condition, though special types of paint must be employed, especially in the vicinity of the anodes attached to the hull. Alternatively, current from the ship's own generators may be discharged through a series of anodes attached to the ship or to a trailing anode. Mention is also made of "mothballing naval vessels," changes in the rate of corrosion due to the different degrees of salinity of the sea, and the affect of anodic protection on fouling.

Protective Zinc Anodes. (*Ind. Fin.*, 1957, **9**, Sept., 814–816). The principles of cathodic protection are discussed and the superiority of high-purity zinc for buried pipe lines and marine applications is emphasized.—A. D. H.

A Relationship between the Current of Cathodic Protection and the Stray Current in Underground Metal Pipes. S. Minc and Z. Feldblum. (*Arch. Elektrotech.*, 1956, **5**, (2), 251–262). The current required for protection can be deduced from the relationship found, which has been confirmed experimentally. A correction for the corrosive effect of the soil is introduced.

ANALYSIS

On the Influence of Water Vapour on the Gas Volumetric Determination of Carbon in Iron and Steel. R. Kraus. (*Giesserei, Tech. Wiss.*, 1957, (17), July, 935–938). The hypothesis of a 100% water vapour saturation of the combustion gases in the old gas-volumetric determination of carbon in iron and steel in the literature is outlined (7 references). The effect of ignoring the degree of saturation by water vapour for different cases is considered. The effects are considered with numerical examples.—B. J. W.

The Molybdate Method for the Determination of Phosphorus, Particularly in Basic Slag and in Steel. D. Stockdale. (*Analyst*, 1958, **83**, Jan., 24–36). Both gravimetric and volumetric methods are given, with a comparison with other procedures.

The Determination of Boron in Carbon and Low-alloy Steels. B.I.S.R.A. Methods of Analysis Committee. (*J.I.S.I.*, 1958, **189**, July, 227–232). [This issue].

On One Method of Micro-Spectral Analysis. I. L. Mirkin and E. P. Rikman. (*Zavods. Lab.*, 1957, **23**, (11), 1338–1341). [In Russian]. A description is given of a method of local analysis with the aid of a "point" source H.F. current rectified with a kenotron rectifier. The diameter and depth of the crater produced by the sparking are about 0·1 mm and a few μ. Results obtained for local Mg-determination in a Mg-inoculated cast iron with spheroidal graphite, and for local Nb, Mo, Ti, Mn, Ni and Si determinations inside and on the boundaries of grains in two complex-alloyed austenitic steels are given.

Spectrophotometric Silicon Determination in Alloy Steels Using Stannous Oxalate as Reductant. M. T. Hall. (*Chem.-Analyst*, 1957, **46**, Sept., 64, 66).

Experience in the Use of Calculated Curves in the Spectral Analysis of High-Speed Steel and Type AZh-9-4 Bronzes. R. I. Kushaeva and A. V. Kungurova. (*Zavods. Lab.*, 1957, **23**, (11), 1357–1360). [In Russian]. Not having the full range of standard samples the authors used the method of I. S. Fishman for calculating calibration curves for the analysis of high-speed steels types R18 and R9 and a bronze. They obtained satisfactory results.—S. K.

Testing of the "FIAN" Spectral Installation for the Determination of Phosphorus in Steel. L. M. Ivantsov, I. I. Konstantinov, V. V. Sukhovalova and A. I. Shurygin. (*Zavods. Lab.*, 1957, **23**, (11), 1329–1332). [In Russian]. The design and extensive testing of the second model of a spectroscopic instrument developed by the Physical Institute of the Academy of Science of the USSR for phosphorus determination in steels is described. Satisfactory results were obtained but the instrument is somewhat unreliable.—S. K.

Influence of the Structure of Type VL7-45U Alloy on the Results of Spectral Analysis. I. A. Grikit. (*Zavods. Lab.*, 1957, **23**, (11), 1341–1346). [In Russian]. The results of spectroscopic analysis of a heat-resisting alloy (20·58%–21·76%Cr, 7·44–9·19%W, 29·73–31·22%Fe, 0·68–0·75%Mn and 1·18–1·29%Si) are related to the structure of the specimen, the material of the electrode and sparking conditions. The influence of structure was less when preliminary sparking was continued for some time since this tended to destroy even the central parts of dendrites. The effect was accelerated when a copper electrode with a small radius of curvature was used. It is concluded that oxidation processes could not explain the influence of structure on the results.—S. K.

Influence of Nitriding on the Results of Spectral Analysis and a Method of Eliminating the Observed Effect. I. A. Grikit. (*Zavods. Lab.*, 1957, **23**, (11), 1347–1351). [In Russian]. In the experiments reported spectroscopic determinations of Si, Cr, Mn, Ni, Mo and Al in types 38KhNMA and 40KhNMA steel subjected to various forms of heat treatment and to nitriding were carried out under various conditions. The absolute intensities of spectra were always greater for nitrided specimens, the relative intensities of lines

due to different elements varying with time. From measurements of crater dimensions it was shown that the nitrided materials participate to a greater extent in the discharge and, metallographic study of the spark spot indicated that a 15-min sparking with a copper electrode destroys the nitride phase.

Suggested Method for Spectrochemical Analysis of Basic Open-Hearth Slags for Lime-Silica Ratios by the Powder-Spark Technique. E. H. Lucas. (*Amer. Soc. Test. Mat. preprint*, 1957, (55), 45–49).

Volatilisation Process in the Cup-Electrode Solution Arc Source and Spectrographic Analysis of Open-Hearth Slags. H. I-Djen, W. Thang-Soo and L. Shih-Cho. (*Acta Chim. Sinica*, 1957, **23**, (3), 159–168). [In Chinese with English summary].

Reproducibility of Spectral Analyses of Slags Using Spark Producers of Different Designs. V. V. Nelimov. (*Zavods. Lab.*, 1957, **23**, (11), 1351–1355). [In Russian]. The analysis of O.H. slags under conditions kept constant except for the type of spark producers used is reported. Details of the design are given and reproducibilities of results obtained with each are compared.—S. K.

On the Organization of Laboratories for Work with Radioactive Isotopes. N. I. Leshchinskii, A. S. Shtan' and V. I. Sinitsin. (*Zavods. Lab.*, 1957, **23**, (11), 1396–1398). [In Russian]. The authors discuss ways of avoiding health hazards in metallurgical and other laboratories in which radioactive isotopes are used. They criticize some recent suggestions.—S. K.

INDUSTRIAL USES AND APPLICATIONS

Materials for Helical Compression Springs for Use at Constant Deflection from 600–1400° F. R. S. Matters and R. E. Lochen. (*Proc. A.S.T.M.*, 1956, **56**, 672–686). Six iron alloys and 3 others were studied and an effective residual stress is calculated and suggested as a guide for design, though it does not apply to springs of very different sizes. The best material found up to 1200° F was a Co-Cr-Ni alloy, but at lower temperatures, some austenitic steels were satisfactory.

Notes on the Properties, Application, and Examination of Ferrous Metals Used in Colliery Engineering. J. Pettit. (*Min. Elect. Mech. Eng.*, 1958, **38**, Jan., 195–203). Tests are outlined and relevant British specifications are quoted and uses and tests in use are discussed.

Metallurgical Progress and the Steam Engineer. L. Sanderson. (*Steam Eng.*, 1958, **27**, Feb., 147–149). A brief account of new developments including a heat-resistant steel bolt, a new Ni-Fe-Cr corrosion-resisting alloy, an austenitic steel with Cr partly replaced with Mo, vacuum-melted and high-strength structural steels and a low carbon Mo steel with B, and notes on cracking and other failures are given.

Control of the High-Temperature Mechanical Properties of Steel Tubes. J. Dauvergne. (*Tech. Mod.*, 1957, **49**, Dec., 685–688). Steels for power stations are reviewed, compositions and mechanical properties are shown with many tensile and other results.

Steels for Tubes Working above 600° C. J. Ivernel. (*Rev. Nickel*, 1957, **23**, April-June, 31–39). Tubes for power stations and nuclear piles are considered, also for petroleum refineries and in the chemical industry. Compositions and creep strengths and temperature resistances are given. The improvement of ferritic steels by treatments or alloy additions, austenitic steels and their properties and problems of production and fabrication, and recarburizing and cracking during treatment are all discussed.

Ferrito-Pearlitic Steels for the Construction of Steam Turbines. R. Pokorny, T. Bužek and T. Kermes. (*Czech. Heavy Ind.*, 1957, (2), 23–29). Data on creep, fatigue, mechanical properties and compositions are given.

Pall Rings: New Type of Tower Packing. J. S. Eckert, E. H. Foote and R. L. Huntington. (*Chem. Eng. Prog.*, 1958, **54**, Jan., 70–75). Carbon steel Pall and Rashig rings are described and tests are quoted. The rings are intended for gas-liquid absorption or extraction systems in chemical industry.

The Role of Metallurgy in Atomic Energy Technology, I. A. Blainey. (*J. S. Afr. Inst. Min. Met.*, 1957, **58**, Dec., 226–255). A few references to stainless steel are included.

High-Boron Steels for Nuclear Reactors. (*Times Rev. Ind.*, 1958, Feb., 40, 43). Development of the steel for control rods, effects of Al, casting methods, rolling and extrusion and the properties of the materials with and without mild steel cladding are discussed.

Steel for Nuclear Energy. R. C. Dalzell. (*Industrial Atom: U.S. Atomic Energy Commission Tech. Inf. Service*, 1956, July, TID-8012, pp. 6). A brief review of stainless steel requirements for reactor construction with tables of absorption cross-sections of probable alloying elements. The monograph is concerned to put in perspective the uses to which the steels can be put and the amount of activation they may acquire.

HISTORICAL

The Centenary of the Open Hearth Furnace and Siemens-Martin Steel. J. E. Lafon. (*Mét. Constr. Mécan.*, 1956, **88**, Nov., 939–941, 943, 945, 947, 949, 950, 953, 955). A general review of the development of the O.H. furnace from 1856 to 1956 is presented.

Early Industrial Production of Bessemer Steel at Edsken. P. Carlberg. (*J.I.S.I.*, 1958, **189**, July, 201–204). [This issue].

Several Investigations on Cast Iron Pipes of Historic Interest. A. Wittmoser. (*Giesserei*, 1957, **44**, Sept. 26, 557–563). The historical development of cast iron pipes from the end of the 14th century to the present day is traced. Investigations were carried out on four old pipes, dating from 1450 to 1850 and two of modern manufacture (1950). Their chemical compositions are tabulated, together with their physical properties. The different methods of manufacture are discussed, together with their metallographic texture and corrosion behaviour.—B. J. W.

The Follonica Foundry and the Medici Family. B. Boni. (*Fond. Ital.*, 1957, **6**, Oct., 393–401). [In Italian]. An historical note which describes the activities of the Follonica Foundry in the 16th Century and its impact on the famous Tuscan Medici family.

Old Forges Previously in North and West Bothnia. P. Norberg. (*Blad Berg. Vänner*, 1957, **3**, (7), 99–358). [In Swedish.]

Forging in the Past. II. R. C. Benson. (*ESC News*, 1957, **11**, Christmas, 6–11). An account of puddling, piling and welding, and a summary of plant in 1869 is given.

ECONOMICS AND STATISTICS

Annual Review of Activity in the Iron and Steel Industry. G. Grenier. (*Echo Mines*, 1958, Jan., 39–41). Statistical.

Iron and Steel Needs of Argentine. J. B. de Nardo. (*Met. Prog.*, 1958, **73**, Jan., 109–111). In the period 1960–1970 the annual steel consumption is predicted as 1,200,000 metric tons. At the moment 30% of the iron and steel is produced internally and future deficits will be reduced when the San Nicolas plant is in production.—B. G. B.

MISCELLANEOUS

Rearrangement of the Management of Industry and New Problems before Works Laboratories. O. L. Bendryshev. (*Zavods. Lab.*, 1957, **23**, (10), 1275–1277). [In Russian]. The author suggests that the recent decentralization of the control of industry and research in the USSR presents works laboratories with increased opportunities and obligations. He recommends the abandonment by consumer-laboratories of selective testing work of certified incoming materials to give more opportunity for helping the introduction of new technological methods in their works, and gives examples from his works, where the control of the works laboratory has been transferred from the chief metallurgist to the works manager. Local branches of research institutes, in their turn, would have more time for research work. He urges the supply of suitable equipment to works laboratories.

Materials Handling. A. Vierling. (*V.D.I.Z.* 1958, **100**, Jan. 11, 71–74). A review is given of developments, during 1957 in the design and production of conveyor belts, coal handling equipment, hydraulic transport, assembly lines, etc. (42 references).—L. J. L.

Chromium. L. Sanderson. (*Can. Min. J.*, 1958, **79**, Jan., 78–79). A review of properties, processes of production and uses.

Electrolysis of Molten Manganese Slags. O. A. Esin, G. A. Toporishchev and P. M. Shurygin. (*Izvest. Akad. Nauk, Otdel. Tekn.*, 1957, (5), 85–91). [In Russian]. In view of the fact that available data on the cathodic process during the electrolysis of Mn slags are only approximate, the authors attempted to apply an improved experimental method in order to establish the main causes determining the current efficiency. The description of the apparatus, experimental procedure and the composition of slags tested are given. It was established that under certain conditions of electrolysis, Faraday's laws are followed at both cathode and anode. It was found that the reduction of the ions Mn^{3+} and Fe^{3+} is the basic cause of a decrease in the current yield of Mn. The action of these ions is considerably greater than the action of Fe^{3+} ions during the electrolysis of iron slags. It was shown that an increase of the ratio of the height to diameter of cathode cells slows down the convective diffusion of Mn^{3+} and Fe^{3+} ions and increases current efficiency. CaO additions to Mn slags also have a beneficial influence. This action is explained by an increase in the viscosity which decreases the convective diffusion of Mn ions. It was noticed that from Mn slags containing small amounts of iron oxides at low current densities, mainly iron is deposited on the cathode and at increased current densities mainly Mn. The existence of a heterogenous equilibrium:

$$2Mn^{3+}\,(slag) + Mn(Ag) \rightleftharpoons 3Mn^{2+}\,(slag),$$

similar to that found for iron slags was established. It is pointed out that the solution of silver in the melts tested is not related to the degree of oxidation of slag, but is directly proportional to the slag volume. The view is expressed that silver passes into slag not in the ionic but in atomic or colloidal form.—V. G.

An Investigation of Vanadium Slags Suitable for the Production of Vanadium. A. Yu. Polyakov and A. V. Rudneva. (*Izvest. Akad. Nauk, Otdel. Tekn.*, 1957, (4), 45–53). [In Russian]. Mineralogical and X-ray studies of slags containing 9·92–25·75% of V_2O_3, 12·25–30·40% of SiO_2 and 0·67–21·35% of Cr_2O_3, obtained by blowing pig iron with air, were carried out. It was established that the only crystalline phase containing V was vanadium spinel. The characteristic feature of this is the stability of its content of R_2O_3 oxides.—V. G.

Making Packages Better, Cheaper. J. L. Haddock. (*Steel*, 1957, **141**, Dec. 23, 80–82). Improved methods for packing tube products are described. These include: bundles, paper drums, palletised crates, skid-racks. Packaging may be combined with inspection. Customer-appeal of packing may increase sales.—D. L. C. F.

ERRATA

Vol. 186

P. 292, col. 1, line 6:
For "Skull" read "Shull."
P. 300, col. 2, line 35 from the bottom:
For "Kiingawa" read "Kitagawa".
P. 379, col. 2, line 20 from the bottom:
For "Hogben, J. A. Spencer" read "Hobgen, K. A. Spencer".

BOOK NOTICES

"ANHALTSZAHLEN FÜR DIE WÄRMEWIRTSCHAFT IN EISENHÜTTENWERKEN." Auflage 5. Herausgegeben von der Energie-und Betriebwirtschaftsstelle des Vereins Deutscher Eisenhüttenleute. 10 × 7 in., pp. xii + 472. Illustrated. Düsseldorf, 1957: Verlag Stahleisen M.B.H. (Price DM. 62).

This is the fifth edition of a work which sets out to provide a compendium of useful information in the form of physical tables and figures about heat and energy in the manufacture of iron and steel or, "Reference Data for Heat and Energy Economics in Iron and Steel Works," as the title may be translated. In fact, its coverage is even more extensive than this suggests. Every step in production in an integrated works is systematically analysed from the viewpoint of the user of heat and energy, standard dimensions and working data are frequently given for equipment as used in Germany, and there is a wealth of information in the form of graphs, tables and figures which the minimum amount of text serves to explain. This *practical* nature of the work is illustrated in the section dealing with ore treatment where, for instance, data for four sinter machines are given. Similarly, in the section on coke, a coke swelling index is provided and, elsewhere, the relationships between size and output for blast furnaces and different kinds of steelmaking furnaces are given.

There are 20 different sections and the subjects treated in these include fuels, combustion, coke ovens, gas producers, ores, blast furnaces, converters, open-hearth furnaces, foundries, electric melting, reheating, heat treatment and miscellaneous industrial furnaces, plastic deformation, power production, oxygen plants and blowers and compressors of many kinds, air purification, total heat consumption, physical constants and conversion tables. The scope of the book is made even wider by a section which gives calculations of muscular effort and ergonomics. In this section such things as noise in different occupations, permissible concentration of gases in working conditions and heating, ventilation and lighting requirements are given. There are 423 tables and 258 figures as well as name and subject indexes and 440 classified references to the literature.

The book is attractively produced and will be of considerable value to fuel users in Germany although there appears to have been some carelessness in reading proofs. Thus, misprints have been noticed on page 363 where Kcal/mh°C should read Kcal/m², the density of hydrogen should read 0·0899 instead of 0·899, Bild 19/6 should read Bild 19/5 and Bild 19/7 should read Bild 19/6. The authors appear to be somewhat unfamiliar with the latest British standards and on pages 435 and 436 B.S.A. should read B.S. In general, this is a valuable addition to reference literature but its limited discussion of British standards and practices and its high price make it much less useful in this country than in its country of origin.—M. L. P.

BONZEL, M., "*Le Tréflage de l'Acier*," Deuxième édition. 9¾ × 6¼ in., pp. xiii + 589. Illustrated Paris, 1958: Dunod. (Price 6400 fr.).

The first edition of this book appeared in 1934. When this was translated into English, the translator had the following to say—". . . the reader will do well to keep constantly in mind that M. Bonzel . . . is describing . . . wet drawing . . . [which] is still the typical practice of France . . ." Since then, wire manufacture even in the then more advanced countries has undergone profound changes and although the author has taken note of them in revising the book, he has not deemed it necessary to alter layout or apportionment of space to the topics treated (except for the omission of chapters on administration of a wire mill and on manufacturing costs). In other words, the original bias towards wet drawing practice with liquor finish has not been changed.

Readers brought up on British or American specialised technological books will be surprised at the inclusion of material only remotely connected with the subject, e.g. an elementary outline of steel-making, chemistry of fats and derivatives, physical chemistry of furnace atmospheres, and the like. They will also be struck unfavourably by the cavalier treatment of sources of information: no references are given in the text, and references quoted at the end of chapters are cursory, incomplete, and sometimes faulty. Indeed it is difficult to decide when reading a passage, whether it is based on experience, someone's investigation published more fully elsewhere, or on the author's unpublished researches. The space allocated to an index in Anglo-Saxon textbooks is taken up here by advertisements.

These shortcomings notwithstanding, the book contains a fund of up-to-date information on both practice and theory of wire manufacture, the chapters on lubrication and heat treatment being most prominent in this respect, and the author's views on most aspects are authoritative. To sum up, a somewhat untidy book, but worth consulting by everyone concerned with the subject and especially by those seeking enlightenment on wet drawing for finishing.

J. G. WISTREICH.

MCLEAN, D., "*Grain Boundaries in Metals*." Monographs on the Physics and Chemistry of Materials. 8¼ × 5¼ in., pp. x + 346. Illustrated. Oxford, 1957: Oxford University Press. (Price 50*s*.).

Dr. McLean has produced an outstanding book. There is little doubt that it will quickly be recognised as a standard work in scientific metallurgy—one of the few.

A very broad approach to the title has been adopted so that there are, in fact, few topics in basic physical metallurgy quite untouched by this book. The structure and energy of the grain boundaries form the starting point. This leads to a chapter on the microstructure of polycrystals and one on the solubility at, and thermodynamics of grain boundaries. Other chapters deal with the effect of the grain and sub-grain boundary on the yield stress, strain-hardening, creep and fracture of metals. Diffusion along, and sliding at grain boundaries are fully discussed and there is a good chapter on the migration of boundaries, with recrystallisation as one important aspect.

The book is a pleasing blend of theory and experiment and the discussion is consistently at the frontier of current knowledge. The number of references on each page is evidence of how fully the literature is covered, but this is no mere reporting; all the work is critically considered, so that the author makes a personal contribution to practically every topic discussed. The reviewer may perhaps mention that he disagrees with the contribution on p. 188.

The general presentation of the book follows the usual refined standard of the O.U.P.—N. J. PETCH.

PHILLIPS, ARTHUR L., (editor). "*Welding Handbook*." Fourth edition, 9¼ × 6 in., pp. vi + 11 chapters, [not continuously paginated]. New York, London, 1957: American Welding Society; Cleaver Hume Press Ltd. (Price 72*s*.).

The Welding Handbook published by the American Welding Society has long held pride of place as the principal vade mecum of the welding metallurgist and engineer. During the immediate post war period there was a tendency for welding practice in this country to follow that in the United States, usually with an appreciable time lag. Reference to the Welding Handbook was often all that was necessary for the welding engineer to keep abreast of the latest practice in this country. In the last few years, however, the gap between the standards of welding technology in the two countries has been closing rapidly and welding practice in Britain has often been in advance of that outlined in the 1954 edition of the Handbook. The publication of a new and completely revised edition will be received, therefore, with great interest.

Welding technology has grown in complexity at a tremendous pace in recent years and in recognition of this the Welding Handbook has been largely rewritten and is to be issued in five parts. Part I deals with Basic Principles and Data and is mainly concerned with welding metallurgy in all its aspects including inspection and testing as well as physical metallurgy and heat treatment. Chapters are also included on standard definitions, joint preparation and costing. The presentation of the subject matter is lucid and concise. The information contained in each chapter is comprehensive and has been reviewed and edited by a chapter committee composed of prominent workers in the field of activity falling within the scope of the chapter. This procedure has ensured a meticulous attention to detail which would have been practically impossible for any author to achieve single handed. Many useful tables are included in the various chapters, a particularly valuable one on the weldability of various steels being contained in Chapter 5.

The chapter on welding metallurgy, which is 114 pages long, would be almost adequate as a short text book on general metallurgy in its own right, but the authors do not lose sight of the fact that it is part of a work on welding and gently, but firmly, return to the subject of welding metallurgy after the necessary general discussion.

The revised Handbook can be recommended, without reservation, as a source of reference to any metallurgist or engineer who is concerned with welding in any of its applications.

From the aspect of technological progress it is interesting to reflect that while the sheer omniscience of the book will engender a feeling of awe it is unlikely to give rise to any sense of inferiority in its British readers. On the contrary, it does little more than reflect present practice in this country and the disparity between the standards of welding technology in Britain and America would seem to have disappeared. In fact, although a short section on welding in nuclear power applications is included in the present volume its treatment is such that one is tempted to believe that this Country may be in the lead in this particular field of welding.

W. I. PUMPHREY.

RESS, FRANZ MICHAEL. "*Geschichte der Kokereitechnik*." 12 × 8½ in., pp. 672. Illustrated. Essen, 1957: Steinkohlenbergbauverein. Verlag Glückauf. (Price DM. 148–).

This is a massive book of 672 pages, 12 by 8½ in. (proposed ISO A4 size), weighing 6 lb, which covers the development of all branches of coke-oven technology in the comprehensive manner almost peculiar to German scholars. It is no dry-as-dust compilation but bears the mark of sound historical research; it is generously illustrated; the sources of information are world-wide so that it represents the development of coke making in all countries; it is comprehensively indexed with over 1000 names and nearly as many subjects; it is therefore a work of reference which should be accessible to all who are interested in coke-oven technology and the working up of its by-products, tar, benzole, ammonia, gas etc.

After a preliminary survey of development (which does full justice to British contributions, including the most important of all—that of Abraham Darby I in 1709) there is a short but sound story of coal cleaning, over 100 pages on coke making without recovery of by-products in heaps and bee-

hive ovens (both English developments, with many new records) and flame ovens (the peculiar contribution by the Belgians and French). The early history of by-product coking (in which the many German contributions are naturally well recorded), is followed by an account of the development of modern coking practices (chiefly in the present century), each of these major sections being of about 200 pages.

There are 607 illustrations, some in colour, and including 93 portraits (including 12 British), usually with full name and period, a most welcome addition to historical records. There are some 1400 references, giving authorities; in this respect Ress is an advance of Johannsen ("Geschichte des Eisens"), who failed to give his references. The references, so desirable in a work of this nature, are numbered without an obvious system and it would have been better if the book had been divided into numbered chapters to provide a basis for reference enumeration.

The treatment of by-product recovery is very full so that the book will interest chemists in other industries. A few instances will serve to show the comprehensiveness and authority. On p. 44 is a short history of the life of the Englishman Marsden who developed the stone crusher and his connection with the American firm of Blake, the authority being the Chief Librarian, Leeds Central Library. On page 45 one learns that it was Thomas Carr of Bristol who, in 1870, developed the Carr crusher. The first use of silica (Dinas) bricks is correctly ascribed to W. W. Young of Swansea in 1822, with an acknowledgment of help received from University College, Swansea. An illustration of an oval beehive oven in England in 1757, is derived from the archives in Osnabruck.

The author, the Bergbauverein (who sponsored the publication) and the publishers have produced a book of unique merit which deserves an international reputation.—R. A. Mott.

Thring, M. W. (editor), "*Air Pollution.*" Based on Papers given at a Conference held at the University of Sheffield, September 1956. 8½ × 5½ in., pp. x + 248. Illustrated. London, 1957: Butterworths Scientific Publications. (Price 42*s.*).

This volume contains fifteen chapters contributed by authors who have special knowledge of the various aspects of Air Pollution and is based upon a series of extra-mural lectures given at the University of Sheffield in September, 1956. The contents are arranged in five main sections which define air pollution and its consequences, describe the behaviour and dispersion of chimney gases, methods for the abatement of pollution (including a chapter on the Iron and Steel Industry) and the current state of clean air legislation. Much of the material has been previously published by the authors in various journals and this volume does a service in collecting the information together. The presentation makes it readable to the layman whilst its wide scope serves to broaden the knowledge of the specialist who may not be so well informed on progress in current work in other related fields. With the rapid advances which are resulting from the intensive studies being carried out both in Britain and abroad, it is inevitable that some of the material will become outdated but the production of this volume is both timely and valuable.

There is some lack of balance between the chapters and whilst that describing the influence of Geographical Factors on Air Pollution is generous and well referenced, The Flow of Chimney Gases deserves fuller treatment and, (save for an incomplete mention in the text) is presented without reference to the original paper on which the calculations are based or to any other published work. Whilst bearing in mind the origin and purpose of the papers comprising this volume, some overlap in material is inevitable but attention to this and adequate cross referencing between the chapters would have improved the publication. The Choice of Gas Cleaning Plant represents an addition to the original series of lectures, is well referenced, easy to read and provides recommendations for further reading. There is a misprint in equation 1 of this chapter which presumably should read:—

$$F = f\frac{\pi d^2 \cdot \rho u^2}{8}$$

if it is to be consistent with the following equations and conform to the conventional definition of a drag coefficient. The omission of a definition of the units in the right hand side of equation 9 is likely to mislead a reader unaccustomed to the use of such formulæ and the practice of pressure loss calculations. With these amendments this chapter constitutes a useful addition to the volume.—R. A. Granville.

NEW PUBLICATIONS

"*Achema Jahrbuch*, 1953–1955." Berichte über Stand und Entwicklung des Chemischen Apparatewesens. Herausgegeben von Herbert Bretschneider. 12 × 8½ in., pp. 764 + 83. Illustrated. Frankfurt am Main, 1954: Dechema.

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British Standards Institution. B.S. M. 27, February 1958. "*Non-Fluorescent Magnetic Flaw Detection Inks for Finished Machined Aircraft Parts.*" 13 × 8½ in. pp. 4. Illustrated. London, 1958. The Institution. (Price 4*s.*).

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British Steel Founders' Association, "*Casting in Steel.*" 9 × 6½ in., pp. [iii] + 112. Illustrated. London. 1958: Sir Isaac Pitman & Sons Ltd. (Price 18*s.*).

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"*Deep Drawing Steels.*" Papers at a Regional Meeting conducted by Detroit Section, A.I.M.E. New York, 1958: A.I.M.E. (Price for members $4.00; non-members $6.00.).

"*Electronic Engineer's Reference Book.*" General Editor, L. E. C. Hughes with a foreword by Percy Dunsheath. 7½ × 5 in., pp. 1311. Illustrated. London, 1958: Heywood & Co. Ltd. (Price 84*s.*).

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"*Industry Fights Corrosion. The Proceedings of the Corrosion Convention held at the Central Hall, London, October* 15, 16, 1957." 11½ × 8½ in., pp. xxxi[i] + 108. Illustrated. London, 1958: Corrosion Technology. (Price 21*s.*).

"*Men, Steel and Technical Change.*" By the Industrial Research Section, Department of Social Science, University of Liverpool. Problems of Progress in Industry—I. 8½ × 5½ in., pp. 36. Illustrated. London, 1957: H.M.S.O. (Price 2*s.*).

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Parker, Earl R., *et al.* "*Effect of Residual Elements on the Properties of Metals.*" A series of Five Educational Lectures. Presented to members of the A.S.M. during the National Metal Congress and Exposition, Cleveland, October 8 to 12, 1956. 9½ × 6 in., pp. 217. Illustrated. Cleveland, 1957: American Society for Metals. (Price $4.00.).

"*Proceedings of the First International Conference on Operational Research, Oxford,* 1957. pp. 526. Illustrated. London. 1958: The English Universities Press Ltd. (Price 50*s.*).

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"*Sixth Symposium (International) on Combustion.*" Compiled by the Standing Committee on Combustion Symposia of the Combustion Institute, Pittsburgh, 10½ × 6¾ in., pp. 943. Illustrated. New York; London, 1958: John Wiley & Sons Inc.; Chapman & Hall Ltd. (Price £11 4*s.*).

"*Spectrochemical Abstracts.*" Vol. V. 1952–1953. By Ernest H. S. Van Someren and F. Lachman. 9½ × 6 in., pp. 66. London, 1958: Hilger & Watts Ltd. (Price 20*s.*).

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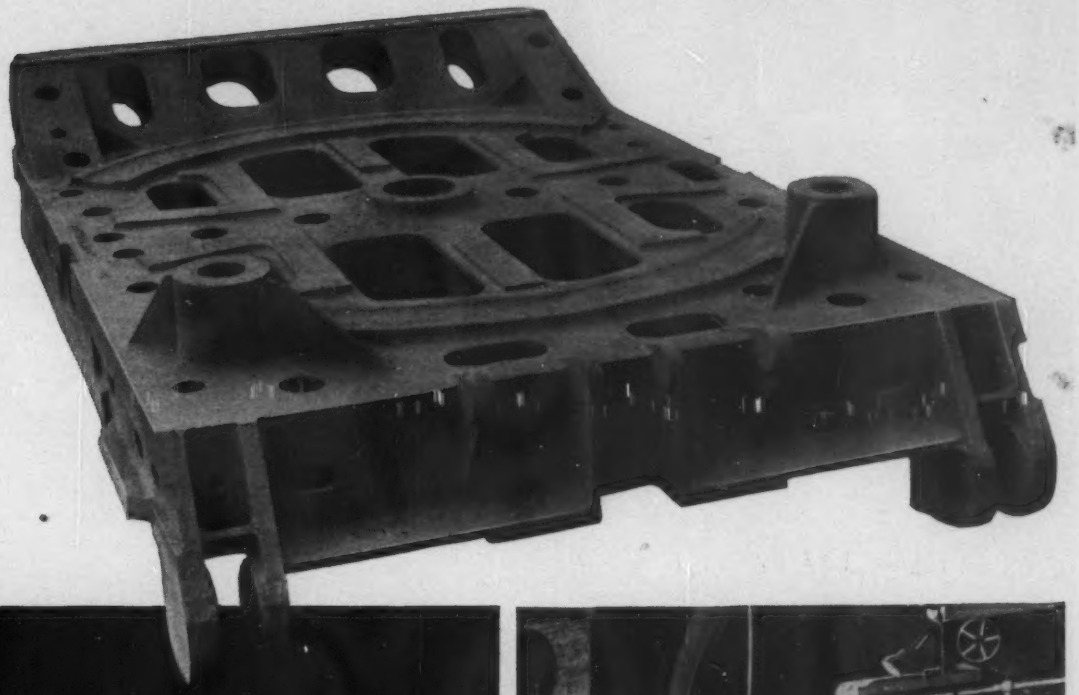

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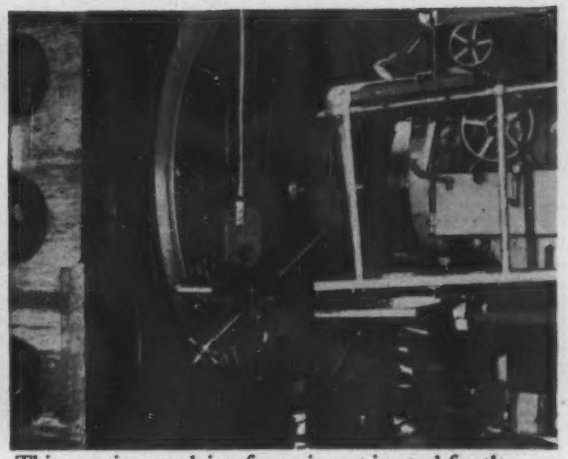

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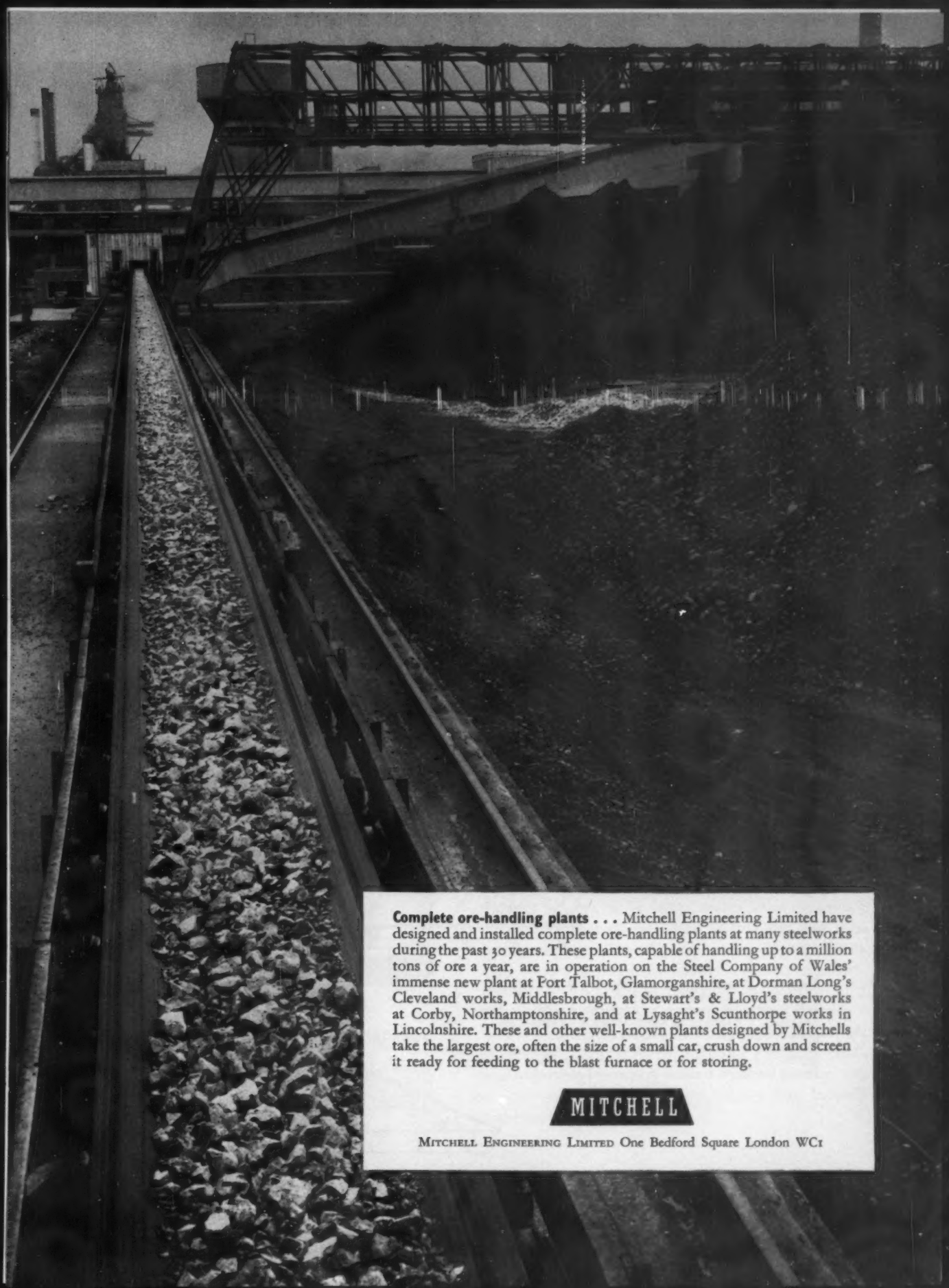

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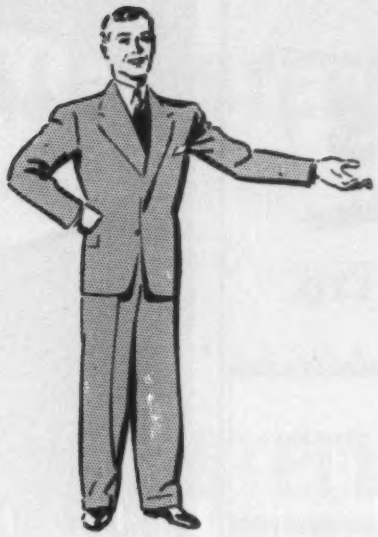

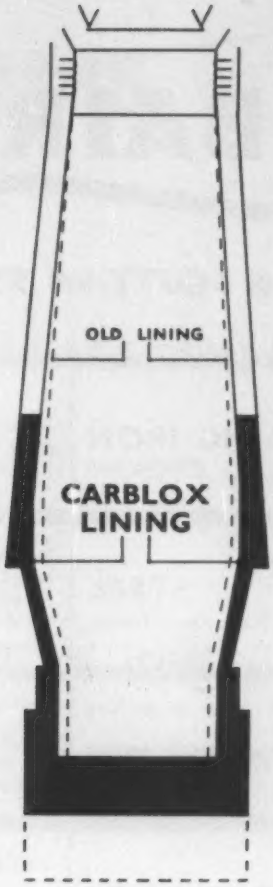

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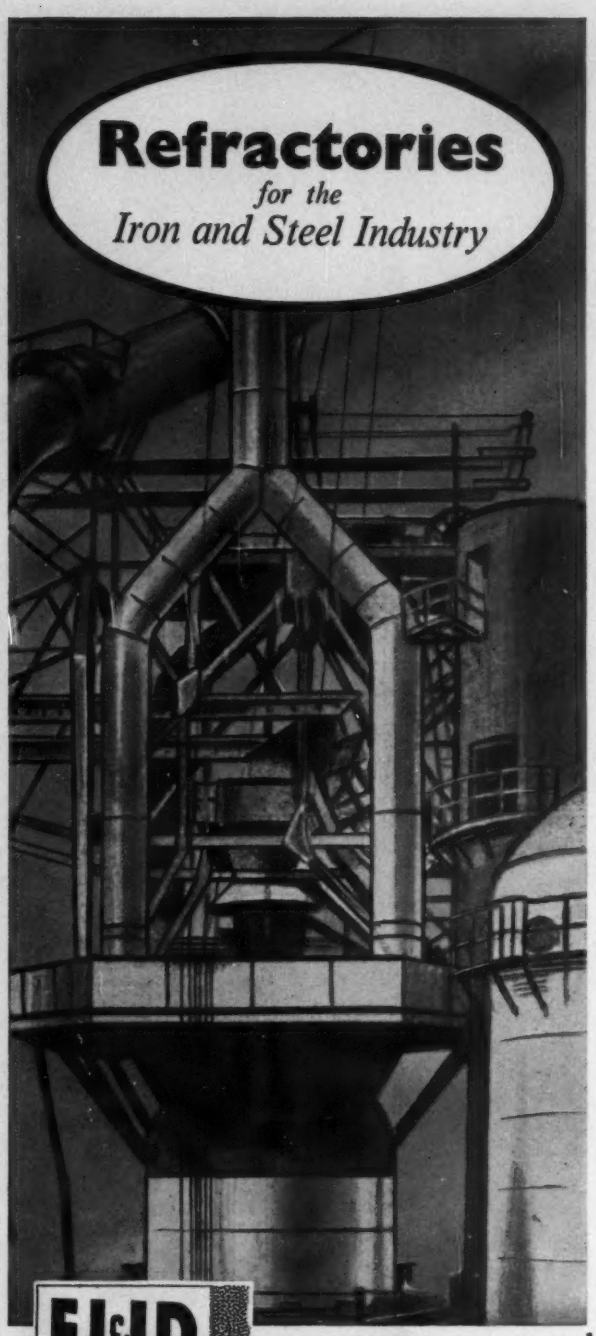

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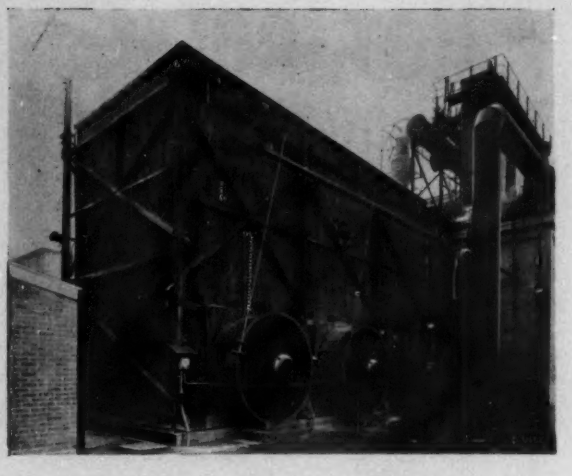

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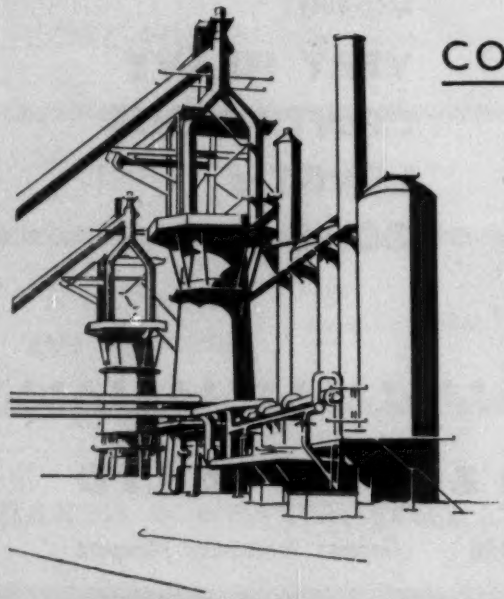

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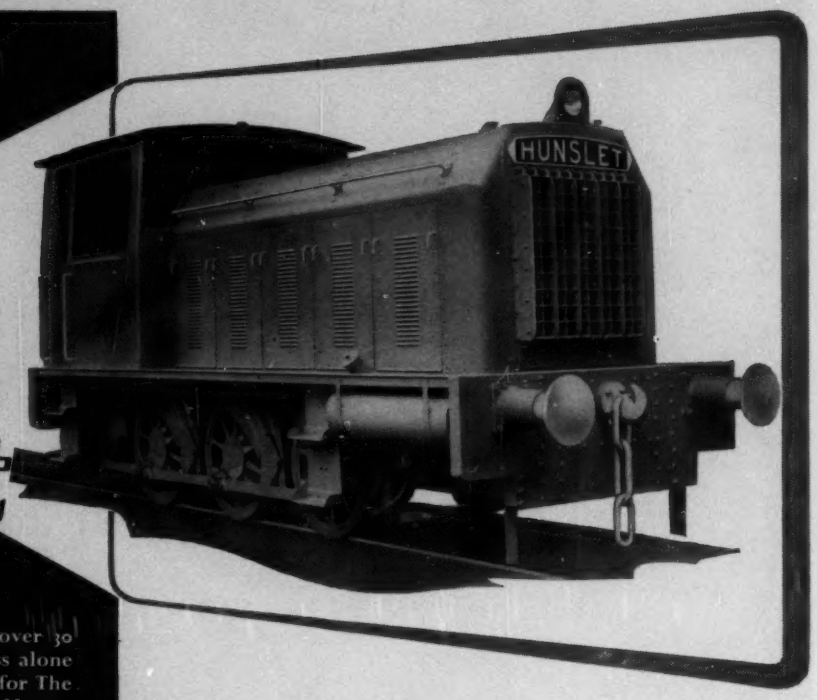

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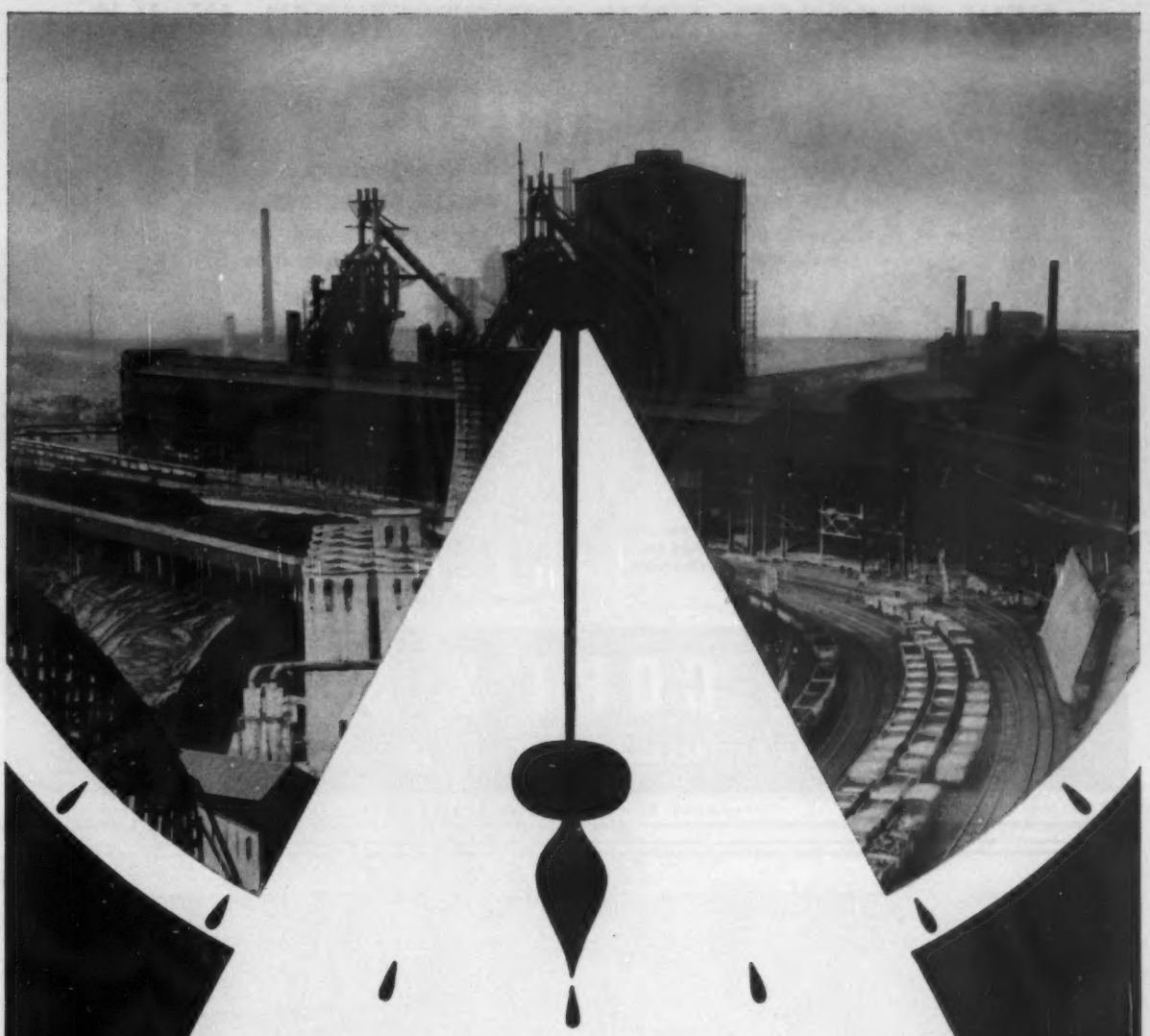

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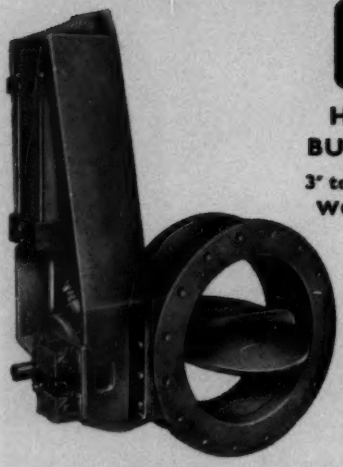

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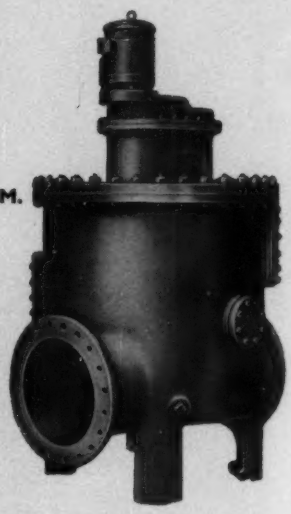

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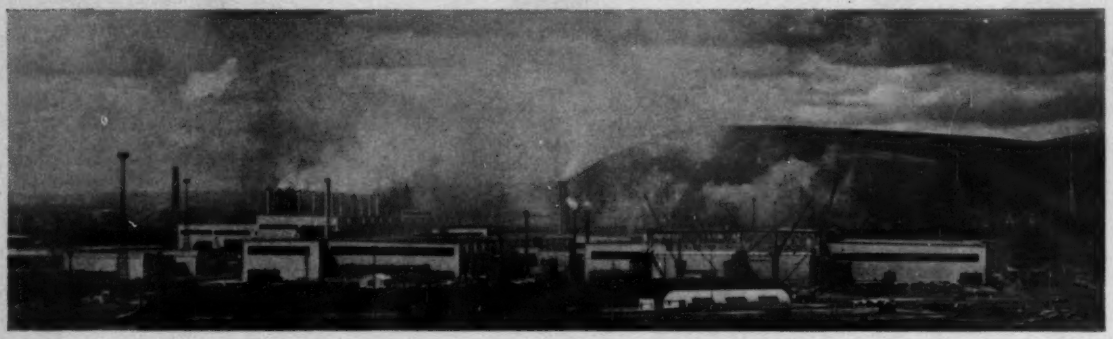

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On 25th-26th September and on 11th-12th December, 1957, in anticipation of the Clean Air Act, 1956 and the Rivers (Prevention of Pollution) Act, 1951 coming into full effect in June and August, 1958 respectively, the Iron and Steel Engineers Group of the Institute held two meetings on Air Pollution and Water Pollution in the Iron and Steel Industry.

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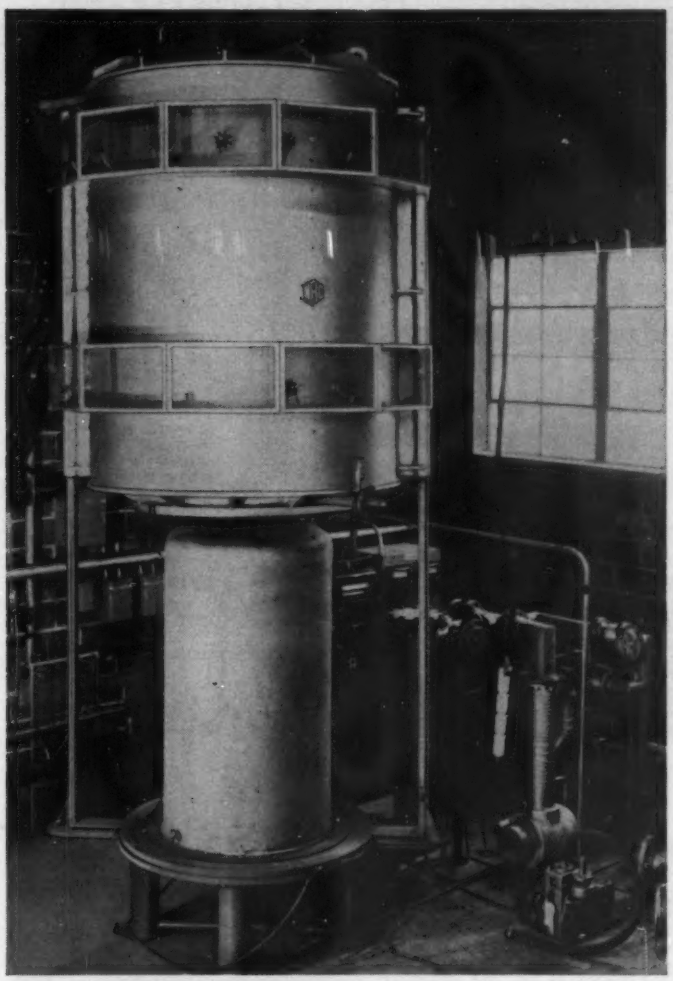

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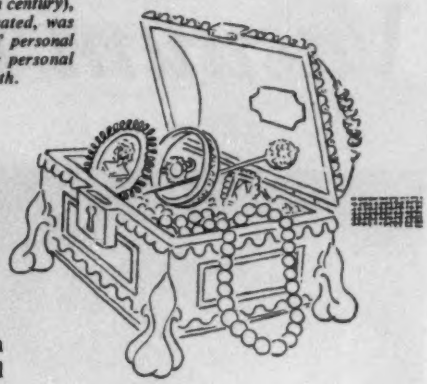

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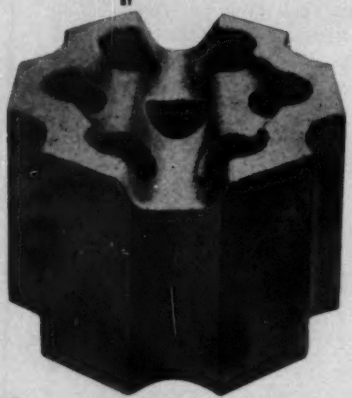

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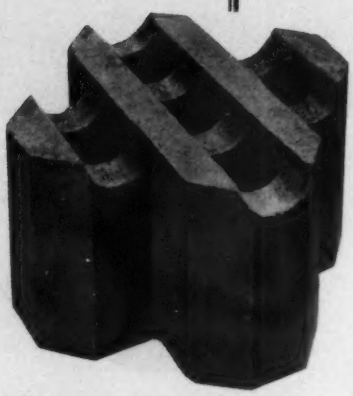

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Index to Advertisers

Adamson-Alliance Co., Ltd. 19
Adamson Joseph and Co., Ltd. ... ... —
Allen West & Co., Ltd. ... ... —
Armstrong Whitworth (Metal Industries) Ltd. ... ... —
Arrol, Sir Wm., & Co., Ltd ... ... —
Ashmore, Benson, Pease & Co. Inside Back Cover

Bairds & Scottish Steel, Ltd. 74
Baker Platinum Division 77
Beardmore, William, & Co., Ltd. ... ... —
Benjamin Electric Ltd., The ... ... —
Bigwood, Joshua, & Son, Ltd. 11
Birfield Industries, Ltd. 53
Birlec, Ltd. ... ... —
Boby, William & Co., Ltd. 5
Boot, Henry, & Sons Ltd. ... ... —
Bradley & Foster, Ltd. ... ... —
Brightside Foundry & Engineering Co., Ltd., The ... ... —
British Acheson Graphite Ltd. ... ... —
British Furnaces, Ltd. ... ... —
British Oxygen Gases, Ltd. ... ... —
British Paints, Ltd. 16
British Rollmakers Corporation, Ltd. ... 23
British Thomson-Houston Co., Ltd., The —
British Timken, Ltd.... ... ... —
Brown Bayley Steels, Ltd. 70
Burn Fireclay Co. Ltd., The 82
Bushing Co., Ltd., The ... ... —

Carblox Ltd. 73
Colvilles, Ltd. 54
Consett Iron Co., Ltd 29
Constables (Matlock Quarries) Ltd. ... —
Contactor Switchgear, Ltd. 39
Coppee Co. (Gt. Britain) Ltd., The ... 5
Cort, Robert, & Son, Ltd 80
Cox & Danks, Ltd. ... ... —
Crofts (Engineers) Ltd. ... ... —
Crooks L. E. ... . —
Crossley Bros., Ltd. ... ... —

Davy & United Engineering Co., Ltd. Inside Front Cover
Dewhurst & Partner, Ltd. 14
D.M.M. Machinery, Ltd. ... ... —
Dollery & Palmer Ltd. ... ... —
Dyson, J. & J. Ltd. ... ... —

Efco-Edwards Vacuum Metallurgy Ltd. 30
Eimco (Gt. Britain) Ltd. 38
Electric Furnace Co., Ltd ... ... —
Electric Resistance Furnace Co Ltd. ... —
Electroflo Meters Co. Ltd Outside Back Cover
English Electric Co. Ltd., The ... ... —
English Steel Corporation, Ltd. ... ... —
Evershed & Vignoles Ltd. 37

Foster, Henry, & Co., Ltd. 18
Foster Instrument Co. Ltd.... ... ... —
Fraser & Chalmers 72
Fuller's Earth Union Ltd., The 41

General Electric Co., Ltd., The ... 20, 21 & 43
General Refractories, Ltd. 1
Gibbons Brothers, Ltd. ... ... —
Glenboig Union Fire Clay Co., Ltd. ... —
Green, E., & Son, Ltd. ... ... —
Guest Keen Iron & Steel Co. Ltd. ... 58
Guest, Keen & Nettlefolds, Ltd. 10
G.W.B. Furnaces, Ltd. ... ... —

Hadfields, Ltd. ... ... —
Hallamshire Steel & File Co., Ltd., The ... 82
Harland Engineering Co., Ltd. ... ... —
Head, Wrightson, Iron & Steel Works Engineering, Ltd. 79
Head, Wrightson Machine Co., Ltd. ... —
Heywood, S. H. & Co., Ltd.... ... ... —
High Speed Steel Alloys Ltd. 78
Holmes, W. C. & Co., Ltd.... 8
Holset Engineering Co., Ltd. ... ... —
Honeywell-Brown, Ltd 40
Howden, James & Co., Ltd ... ... —
Hudswell Clarke & Co., Ltd. 45
Hunslet Engine Co. Ltd. 78
Huntington, Heberlein & Co. Ltd. ... —

Igranic Electric Co., Ltd 44
Ilford, Limited ... ... —
Imperial Chemical Industries Ltd. ... ... —
International Construction Co Ltd., The 26

Johnson's Rolls Ltd. ... ... —
Johnson Matthey & Co., Ltd. ... ... —

Kestner Evaporator & Engineering Co., Ltd. ... —
Kingscliffe Insulating Products, Ltd. ... 49

Lamberton & Co., Ltd. ... ... —
Lanarkshire Steel Co., Ltd., The ... ... —
Lancashire Steel Corporation, Ltd., The ... 50
Lloyd, F. H., & Co., Ltd. 69
Lodge-Cottrell, Ltd. 59
Loewy Engineering Co. Ltd., The ... ... —
Lysaght's John, Scunthorpe Works Ltd. ... 56

Marshall, Thomas, & Co. (Loxley), Ltd. ... —
Metropolitan Vickers Electrical Co., Ltd. 34
Michigan (Gt. Britain) Ltd. 17
Mobil Oil Co. Ltd. 15
Mitchell Engineering Ltd. 71
Mond Nickel Co., Ltd. ... ... —
Moorwood, John M., Ltd. ... ... —
Morgan Crucible Co., Ltd., The ... ... —
Morgan Refractories Ltd. 46
Morgardshammars Mekaniska Verkstads AB —
Moxey, Ltd. 35

Newalls Insulation Co., Ltd. 62
Newell, Ernest, & Co., Ltd. 66
Newton, Chambers & Co., Ltd. 9

Oughtibridge Silica Firebrick Co. ... ... —

Park Gate Iron & Steel Co., Ltd. 22
Parsons, C. A. & Co., Ltd. ... ... —
Pearson, E. J. & J., Ltd. 74
Pergamon Press Ltd. ... ... —
Phillips Electrical Ltd. ... ... —
Pickford Holland & Co., Ltd. ... ... —
Power-Gas Corporation Ltd., The Inside Back Cover
Press, William & Son, Ltd. 27
Priest Furnaces, Ltd. 32

Rawlplug Co. Ltd., The ... ... —
Richardsons Westgarth & Co. Ltd. ... —
Roberts, J. W. Ltd.... 6
Robertson, W. H. A., & Co., Ltd.... ... —

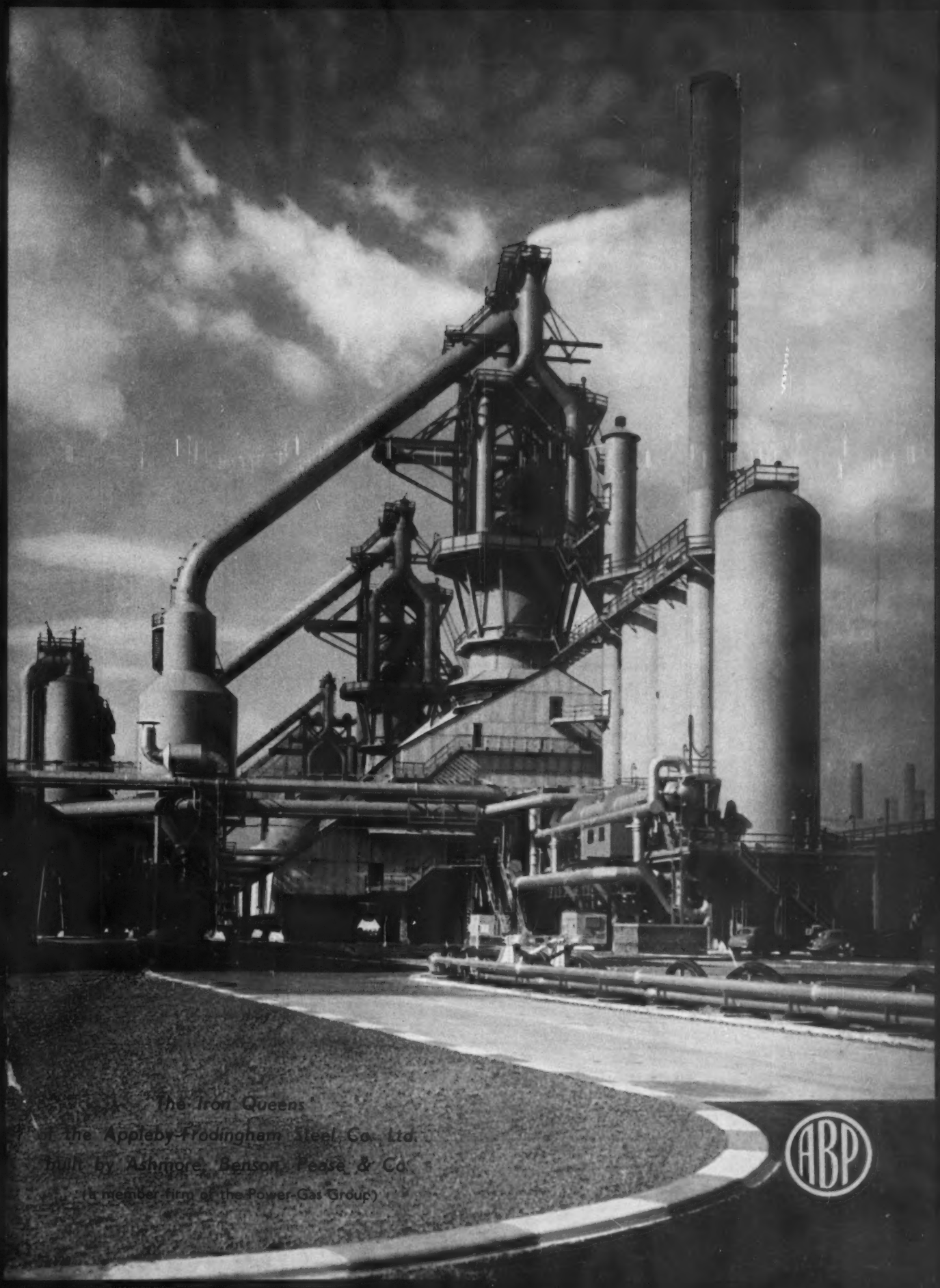
Salem Engineering Co., Ltd. 24
Schloemann ... ... —
Shaw, John, & Sons (Salford) Ltd. ... ... —
Shell-Mex & B.P., Ltd. ... ... 12 & 13
Sheppard & Sons, Ltd. ... ... —
Simon-Carves, Ltd. 33
Smith, John (Keighley), Ltd. 25
Smith Thomas & Sons (Rodley) Ltd ... —
Smith & McLean, Ltd. 48
Spartan Steel & Alloys Ltd. 7
Stanton Ironworks Co., Ltd., The 52
Steel Co. of Wales, The ... ... 2 & 3
Stein & Atkinson, Ltd 4
Stein, John G., & Co., Ltd.... 42
Stephens Silica Brick Co., Ltd 60
Stewarts & Lloyds Ltd ... ... —
Summerson, Thos., & Sons Ltd 55
Sunvic Controls Ltd. ... . —

Tattersall & Son Ltd. 76
Thermal Syndicate Ltd. 63
Thomas (Richard) & Baldwins, Ltd. 61 & 65
Thornton, B., Ltd. 47

Union Carbide Ltd. ... ... —
United Coke & Chemicals Co. Ltd.... ... 83
United Steel Companies Ltd. ... ... —

Vaughan, Edgar, & Co., Ltd. 28
Visco Engineering Co., Ltd. 76

Wallsend Slipway and Engineering Co. Ltd. ... —
Ward, Thos., W., Ltd. 36
Warner & Co., Ltd.... ... ... —
Wellman Smith Owen Engineering Corporation Ltd., The 68
West Hunwick Silica & Firebrick Co., Ltd 51
Whitehead Iron & Steel Co., Ltd.... ... 75
Wiggin, Henry, & Co., Ltd.... ... ... —
Wild Barfield Electric Furnaces Ltd. ... 81
Willan, G. L. Ltd. ... ... —
Wincott, G. P., Ltd.... ... ... —
Woodall-Duckham Construction Co., Ltd. 31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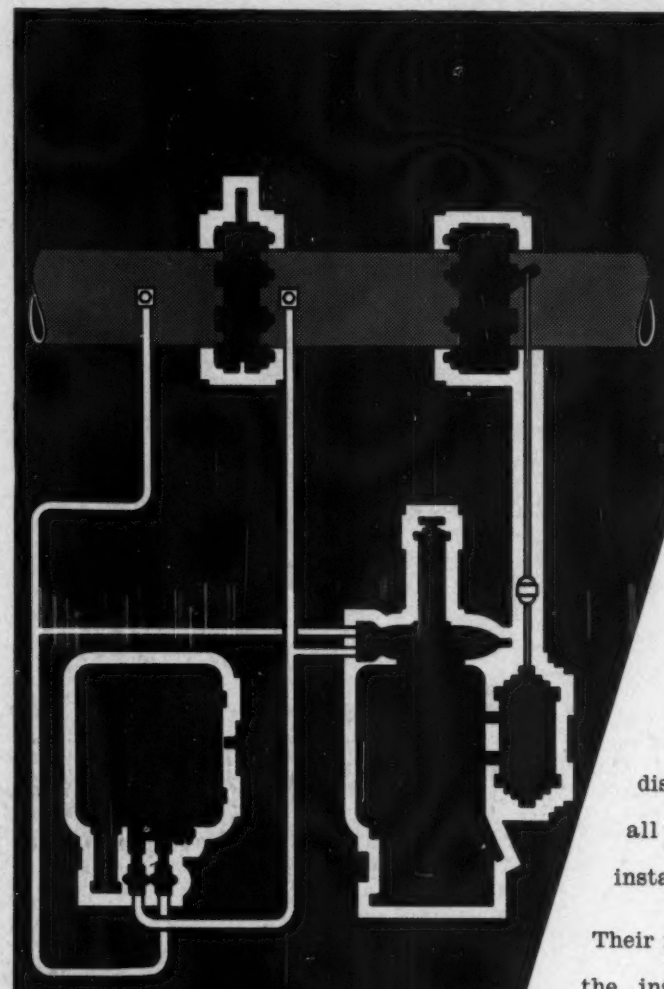

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ELECTROFLO METERS COMPANY LIMITED

Head Office: Abbey Road, Park Royal, London, N.W.10.
Telephone: Elgar 7641/8. *Grams & Cables:* Elflometa, London. *Telex:* Telex No. 2-3196
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